24134

National Library of Canada | Bibliothèque nationale du Canada

CANADIAN THESES ON MICROFICHE | THÈSES CANADIENNES SUR MICROFICHE

NAME OF AUTHOR/*NOM DE L'AUTEUR* Leonard S. P. Song

TITLE OF THESIS/*TITRE DE LA THÈSE* Genetic variability in diallel crosses of alfalfa

UNIVERSITY/*UNIVERSITÉ* University of Alberta

DEGREE FOR WHICH THESIS WAS PRESENTED/ *GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE* Ph.D.

YEAR THIS DEGREE CONFERRED/*ANNÉE D'OBTENTION DE CE GRADE* Spring, 1975

NAME OF SUPERVISOR/*NOM DU DIRECTEUR DE THÈSE* Dr. P. D. Walton

Permission is hereby granted to the NATIONAL LIBRARY OF CANADA to microfilm this thesis and to lend or sell copies of the film.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

L'autorisation est, par la présente, accordée à la BIBLIOTHÈQUE NATIONALE DU CANADA de microfilmer cette thèse et de prêter ou de vendre des exemplaires du film.

L'auteur se réserve les autres droits de publication; ni la thèse ni de longs extraits de celle-ci ne doivent être imprimés ou autrement reproduits sans l'autorisation écrite de l'auteur.

DATED/*DATÉ* April 3, 1975 SIGNED/*SIGNÉ* [signature]

PERMANENT ADDRESS/*RÉSIDENCE FIXE* c/o Department of Crop Science
University of Guelph
Guelph, Ontario

NL-91 (3-74)

THE UNIVERSITY OF ALBERTA

GENETIC VARIABILITY IN DIALLEL CROSSES OF ALFALFA

by

© LEONARD SWEE-PAW SONG

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

IN

PLANT BREEDING

DEPARTMENT OF PLANT SCIENCE

EDMONTON, ALBERTA

SPRING, 1975

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Genetic variability in diallel crosses of alfalfa

submitted by Leonard Swee-Paw Song

in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Plant Breeding.

Supervisor

External Examiner

Date 26th March 1975

ABSTRACT

Three diallel cross populations of alfalfa (*Medicago sativa* L.) were created from thirteen clones which were random selections from thirteen cultivars from widely different origin. Of the three populations, two consisted of F_1s with reciprocals (7-clone and 5-clone diallels) while the third was made up of F_1s only (6-clone diallel). The material was planted in Edmonton and studied for various agronomic and morphological characters between 1972 and 1974.

Genetic variability for all the characters was appreciable. Most of the genetic variation was due to the additive gene action since the variance for general combining ability (GCA) was generally larger than the variance for specific combining ability (SCA). For forage yield, vigor, plant height and days to flower, the results obtained in the second year are expected to be more useful for selection purposes than those observed in the year of establishment. For frost tolerance, the selection of tolerant genotypes should be effective in the year of establishment. Appreciable genetic variability was found for leaflet area and specific leaf weight (SLW) at the early bud stage. Although selection could change the expression of these two characters the practical value of such an approach was questioned since neither character was correlated with forage yield.

Strong genetic correlations were found between forage

yield, vigor, frost tolerance and growth habit. Generally, plants with higher forage yield also had good spring vigor, frost tolerance and winter survival. Such plants also had poor fall vigor and a prostrate growth habit. However, a number of F_1s were found which were good in both spring and fall vigor. Further, there were also some F_1s which combined good fall vigor with frost tolerance and winter survival. Such recombinations of characters suggest that the genetic associations were not due to linkage or pleiotrophy, but was the result of selection. Therefore, a selection program that utilizes the recombination of characters would be successful in regrouping these characters.

Generally, clones selected from adapted cultivars produced progenies that were higher in forage yield, better in frost tolerance and good in winter survival. Therefore clones selected from 'Rambler', 'Roamer', 'Beaver', 'Grimm' and 'Narrangansett' would be of value as parents for synthetics. Results from the five-clone and two-clone experimental synthetics, which involved this genetic material, indicated that such an approach would result in the development of higher yielding strains. The value of using a wider range of material for this area was also demonstrated by the high yields obtained from eleven F_1s. In this case, the parental clones were selected from a divergent range of cultivars of both Canadian and foreign origin.

Differences in general stability, as described by the

regression coefficients of the average performance of the clones on the environmental index, were large. Such differences were less for the F_1s. Thus the regression coefficients were influenced by the variation due to the additive gene action rather than the non-additive gene action. Hence, general stability is genetically controlled and should change in response to selection. Specific instability, as measured by the deviation from the regression line, was also useful in selecting for stability. A number of genotypes in this study showed promise for synthesizing a stable cultivar for use in this area.

ACKNOWLEDGEMENTS

I would like to express my gratitude to the following:

Dr. P.D. Walton for giving me this opportunity to pursue my interest in plant breeding. Also, I would like to thank him for his kindness, help and guidance in various aspects leading to this thesis,

Kurt Kutschera and Hans Jahn of University Farm (Parkland) for their help with field work,

Helge Welling for his assistance with greenhouse facilities,

My wife, Imelda May-Ming, for her understanding and for her help in typing, and

The National Research Council of Canada for its financial support.

TABLE OF CONTENTS

ABSTRACT iv

ACKNOWLEDGEMENTS vii

LIST OF TABLES x

LIST OF FIGURES xvii

I. INTRODUCTION 1

II. LITERATURE REVIEW 3

1. Combining ability 3

2. Association between characters .. 8

3. Stability of the single crosses .. 12

III. MATERIALS AND METHODS 16

1. Materials 16

2. Methods 20

3. Statistical analysis 24

(i) Combining ability 24

(ii) Association between characters .. 26

(iii) Stability of the single crosses .. 29

IV. RESULTS 31

1. Combining ability 31

(a) Forage yield 35

(b) Vigor 42

(c) Frost tolerance and winter survival 48

(d) Growth habit 54

(e) Plant height 58

(f) Days to flower - 1st flower .. 62

(g) Leaflet area and specific leaf weight 67

2. Association between characters 71

(a) Association of the same character between environments .. 71

(b) Association between characters .. 74

(c) Stepwise multiple regression .. 79

(d) Factor analysis 83

3. Experimental synthetics 87

4. Stability of the single crosses 91

V. DISCUSSION 98

1. General combining ability of the parental clones 98

2. Genetic variability of the characters .. 100

3. Association of agronomic characters in the F_1s 107

4. Association of leaflet area and SLW with forage yield 109

5. Experimental synthetics 110

6. Stability of the single crosses 114

7. General discussion 117

VI. SUMMARY AND CONCLUSIONS 121

VII. BIBLIOGRAPHY 124

VIII. APPENDIX 130

LIST OF TABLES

1. Analysis of variance for characters studied in a 7 × 7 diallel cross population .. 32

2. Analysis of variance for characters studied in a 5 × 5 diallel cross population .. 33

3. Analysis of variance for characters studied in a 6 × 6 diallel cross population .. 34

4. Mean squares and F-test values for the combining ability of forage yield in three diallel cross populations of alfalfa .. 37

5. Estimates of GCA effects for forage yield in three diallel cross populations .. 38

6. Estimates of SCA effects for forage yield in a 7 × 7 diallel cross population .. 39

7. Estimates of SCA effects for forage yield in a 5 × 5 and a 6 × 6 diallel cross population 40

8. Forage yield (grams dry matter/plant) of the eleven single crosses that were consistently high and positive in SCA effects in the diallel crosses 41

9. Mean squares and F-test values for the combining ability of vigor in the three diallel cross populations 44

10. Estimates of GCA effects for vigor in the three diallel cross populations 45

11. Estimates of SCA and reciprocal effects for spring vigor (July 1973) and fall vigor (September 1973) in a 7 × 7 diallel cross 46

12. Estimates of SCA and reciprocal effects for spring vigor (July 1973) and fall vigor (September 1973) in a 5 × 5 and a 6 × 6 diallel cross population 47

13. Mean squares and F-test for the combining ability of frost tolerance and winter survival in the three diallel cross populations 50

14. Estimates of GCA effects for frost tolerance and winter survival in the three diallel cross populations 51

15. Estimates of SCA and reciprocal effects for frost tolerance in a 7 × 7 diallel cross population 52

16. Estimates of SCA and reciprocal effects for frost tolerance in a 5 × 5 and a 6 × 6 diallel cross population 53

17. Mean squares and F-test for combining ability of growth habit in a 7 × 7 and a 5 × 5 diallel cross 55

18. Estimates of GCA effects for growth habit in a 7 × 7 and a 5 × 5 diallel cross population 56

19. Estimates of SCA and reciprocal effects for growth habit in a 7 × 7 diallel cross population 57

20. Mean squares and F-test for the combining ability of plant height in a 7 × 7 and a 5 × 5 diallel cross 59

21. Estimates of GCA effects for plant height in a 7 × 7 and a 5 × 5 diallel cross 60

22. Estimates of SCA and reciprocal effects for plant height in a 7 × 7 and a 5 × 5 diallel cross population 61

23. Mean squares and F-test for combining ability of days to flowering in a 7 × 7 and a 5 × 5 diallel cross 64

24. Estimates of GCA effects for days to flowering in a 7 × 7 and a 5 × 5 diallel cross 65

25. Estimates of SCA and reciprocal effects for days to flowering in a 7 × 7 and a 5 × 5 diallel cross population 66

26. Mean squares and F-test for the combining ability of leaflet area and specific leaf weight (SLW) in a 7 × 7 diallel cross .. 68

27. Estimates of GCA effects for leaflet area and specific leaf weight (SLW) in a 7 × 7 diallel cross 69

28. Estimates of SCA effects for leaflet area (upper diagonal) and specific leaf weight (lower diagonal) for Stages I and II combined in a 7 × 7 diallel cross population 70

29. Simple correlation coefficients for forage yield between environments (n = 168) 72

30. Simple correlation coefficients for the same characters between environments (n = 168) 73

31. Simple correlation coefficients for plant height (Greenhouse), forage yield (Greenhouse), leaflet area, specific leaf weight, forage yield (July), vigor and growth habit in a 7 × 7 diallel cross (n = 168) 76

32. Simple correlation coefficients between agronomic characters studied in each year (n = 168) 77

33. Genotypic correlation (r_g) between characters in 1972 and 1973 from a 7 × 7 diallel cross (upper diagonal, n = 42) and a 5 × 5 diallel cross (lower diagonal, n = 20) 78

34. Partial regression coefficients of characters from greenhouse and field (1972) on forage yield of July in 1973 in the order introduced in the stepwise multiple regression (n = 168) 81

35. Partial regression coefficients of characters from field (1973) and morphological characters in 1974 on forage yield of July 1973 in the order introduced in the stepwise multiple regression (n = 168) 82

36. A factor analysis for characters of greenhouse and field (1972) in a 7 × 7 diallel cross population of alfalfa (n = 168) 85

37. A factor analysis for characters of 1973 and morphological characters of 1974 in a 7 × 7 diallel cross population of alfalfa (n = 168) 86

38. Analysis of variance for forage yield (mean of two harvests) in four populations of synthetics at two locations 88

39. Analysis of variance for forage yield in four populations of synthetics at each location 88

40. Forage yield (grams of dry matter/plant) for synthetic populations at each location, and locations combined, in the year of establishment 89

41. Forage yield and winter survival from F_1s evaluated in 1972-74 90

42. Analysis of variance for forage in 7-clone and 5-clone diallels that were studied in 8 environments in Edmonton 93

43. Analysis of variance for forage yield in a 7-clone and a 5-clone diallel that were studied in 8 environments in Edmonton 94

44. Average clone performance in diallel crosses in Edmonton 95

45. Regression coefficients (upper diagonal) and mean square of deviation (lower diagonal) for each F_1 of a 7-clone diallel over 8 environments in Edmonton .. 96

46. Regression coefficients (upper diagonal) and mean squares of deviation (lower diagonal) for each F_1 of a 5-clone diallel over 8 environments in Edmonton 97

APPENDICES

Table I Data from 7 × 7 diallel cross population (Mean values of 16 plants) .. 130

I- 1 Forage yield - Greenhouse (1971/72) 130

I- 2 Forage yield - July, 1972. .. 130

I- 3 Forage yield - July 1973 131

I- 4 Forage yield - September 1973 131

I- 5 Forage yield - July 1974 132

I- 6 Forage yield - September 1974 132

I- 7 Forage yield - July 1974 (Parkland) 133

I- 8 Forage yield - September 1974 (Parkland) 133

I- 9 Forage yield - July 1974 (Ellerslie) 134

I-10 Forage yield - September 1974 (Ellerslie) 134

I-11 Winter survival - 1972/74 135

I-12 Vigor - July 1972 135

I-13 Vigor - July 1973 136

I-14 Vigor - September 1973 136

I-15 Frost tolerance - September 1972 137

I-16 Frost tolerance - September 1973 137

I-17 Growth habit - July 1972 138

I-18 Growth habit - July 1973 138

I-19 Plant height - Greenhouse (1971/72) .. 139

I-20 Plant height - July 1972 140

I-21 Plant height - July 1973 140

I-22 Days to flower (1st flower) - July 1972 141

I-23 Days to flower (10th flower) - July 1972 141

I-24 Days to flower (1st flower) - July 1973 142

I-25 Days to flower (10th flower) - July 1973 142

I-26 Leaflet area (Stage I) - August 1974 143

I-27 Leaflet area (Stage II) - September 1974 143

I-28 Specific leaf weight (Stage I) - August 1974 144

I-29 Specific leaf weight (Stage II) - September 1974 144

Table II Data from 5 × 5 diallel cross population (Mean value of 16 plants).. 145

II- 1 Forage yield - July 1972 145

II- 2 Forage yield - July 1973 145

II- 3 Forage yield - September 1973 145

II- 4 Forage yield - July 1974 146

II- 5 Forage yield - September 1974 146

II- 6 Forage yield - July 1974 (Parkland) 146

II- 7 Forage yield - September 1974 (Parkland) 147

II- 8 Forage yield - July 1974 (Ellerslie) 147

II- 9 Forage yield - September 1974 (Ellerslie) 147

II-10 Winter survival - 1972/74 148

II-11 Vigor - July 1972 148

II-12 Vigor - July 1973 148

II-13 Vigor - September 1973 149

II-14 Frost tolerance - September 1972 149

II-15 Frost tolerance - September 1973 149

II-16 Growth habit - July 1972 150

II-17 Growth habit - July 1973 150

	II-18	Plant height - July 1972	150
	II-19	Plant height - July 1973	151
	II-20	Days to flower (1st flower) - July 1972	151
	II-21	Days to flower (10th flower) - July 1972	151
	II-22	Days to flower (1st flower) - July 1973	152
	II-23	Days to flower (10th flower) - July 1973	152
Table III		Data from 6 × 6 diallel cross population (Mean value of 16 plants)	153
	III- 1	Forage yield - July 1972	153
	III- 2	Forage yield - July 1973	153
	III- 3	Forage yield - September 1973	153
	III- 4	Forage yield - July 1974	154
	III- 5	Forage yield - September 1974	154
	III- 6	Winter survival - 1972/74..	154
	III- 7	Vigor - July 1972	155
	III- 8	Vigor - July 1973	155
	III- 9	Vigor - September 1973	155
	III-10	Frost tolerance - September 1972 ..	156
	III-11	Frost tolerance - September 1973 ..	156
Table IV		Data from experimental synthetic populations..	157
	IV- 1	Forage yield - 1974 (Parkland)	157
	IV- 2	Forage yield - 1974 (Ellerslie).. ..	157

Table V Data showing differences between replications 158

V- 1 Characters in 7-clone diallel 158

V- 2 Characters in 5-clone diallel 159

V- 3 Characters in 6-clone diallel 160

I. INTRODUCTION

Most cultivars of alfalfa (*Medicago sativa* L.) are produced as synthetics in which a limited number of parents are allowed to cross-pollinate in isolation. Because the performance of synthetic cultivars is dependent on various factors, the choice of suitable parents is difficult. In Western Canada, a major consideration has been winter survival, disease resistance and a good yield of suitable quality forage. In their search for winter survival and disease resistance, plant breeders placed considerable emphasis on the use of *Medicago falcata* L. Such a priority often excluded the use of genetic materials of good forage yield potential but of little value for winter survival and disease resistance. Since the expression of heterosis depends on the use of divergent germ plasm, and also since the performance of multi-clone synthetics relies on the use of unrelated parents, the possibility of utilizing a wider range of materials in Western Canada should be considered. The cultivars 'Rambler', 'Roamer' and 'Drylander' were produced for use under the dryland conditions at Saskatoon and Swift Current. In view of the fact that such conditions of extreme dryness were seldom experienced in Edmonton, or in certain other parts of Western Canada, the possibility of using a wider range of genetic material to produce a cultivar suitable for use in these areas called for further study.

The objectives of this study were:

1) to survey the value of an extensive range of genetic material under the conditions prevailing in Edmonton,
2) to investigate the combining ability of random selections from these cultivars,
3) to study the interrelationship of various agronomic and morphological characters, and
4) to evaluate the possibility of introducing selection for environmental stability to the production of alfalfa cultivars for use in Western Canada.

II. LITERATURE REVIEW

1. *Combining ability.* The value of an alfalfa clone as a parent for commercial cultivars is determined by two factors: (1) the characteristics of the clone itself with respect to its yield potential, disease resistance, winter survival and quality, and (2) the behaviour of the clone in combination with other clones. The first factor could be attained by selection while the second could be realized by a progeny test (e.g. testing in terms of its combining ability). Clones selected should possess the desirable traits as well as superior combining ability for each of these characters.

Combining ability has been used as a method for selecting superior clones of alfalfa by Tysdal *et al.* (1942) and Bolton (1948). Its use for evaluating forage grasses has been reviewed by Hanson and Carnahan (1956), and for corn and other crops by Hayes *et al.* (1955). Sprague and Tatum (1942) drew attention to the practical value of general and specific combining ability as a means for selecting potential parents in corn. According to them, general combining ability (GCA) was defined as the average performance of a line in hybrid combination, while specific combining ability (SCA) was used to designate those cases in which combinations do relatively better or worse than could be expected on the basis of average performance of

the lines involved. Owing to the way in which these two parameters were calculated, the GCA variance (σ_g^2) describes the additive gene action while the SCA variance (σ_s^2) refers to dominance and epistasis as well as genotype × environment interactions (Rojas and Sprague, 1952). Sprague and Tatum (1942) also pointed out that in a population unselected for combining ability, genes with additive effects were either more common or produce greater effects than genes with dominance or epistatic effects. However, in previously selected materials, genes with dominance or epistatic effects were as important, or more important, than genes with additive effects since the selected lines have a higher degree of similarity in performance than the original population. The relative importance of additive gene action to dominance or epistasis could be determined by the ratio of GCA to SCA variances.

In the last decade or so there have been increasing reports in the literature on GCA and SCA tests for clones based on diallel crosses of alfalfa. In general these results supported the conclusion reached by Sprague and Tatum (1942) and showed that the relative importance of these two sources of variation depended on the nature of the parental clones used. In most diallel crosses of alfalfa in which the parents have not undergone selection for their combining ability, the variance for GCA was more important than the variance for SCA (Carnahan *et al.*, 1960; Dudley,

1963; Theurer and Elling, 1963; Davis and Gartner, 1966). On the other hand, for parents that have been selected for their combining ability, the variance for SCA was more important than the variance for GCA (Evans *et al.*, 1966; Kehr, 1961; Singh and Lesins, 1971). Both types of results are of practical value. Parents identified on the basis of superior GCA effects could form clones for the production of multi-clone synthetic cultivars of alfalfa. Also, any two parents that consistently exhibited high SCA effects could be used as parents for two-clone synthetics.

While selected clones provide an immediate basis for experimental synthetics which may ultimately be commercial cultivars, there is a need for critical studies to determine the nature of gene action for various quantitatively inherited traits. This would pave the way for the development and use of the most efficient breeding system for each character. In this regard there are two areas in which very little work has been done. These are characters that relate to survival or fitness, and those that indicate the photosynthetic rate of the alfalfa plant.

Various workers have assessed plant height, vigor and growth habit to describe the combining abilities for these traits. Dudley *et al.* (1969) measured plant height, spring and fall growth habit, as well as recovery after cutting, in a population of 'Cherokee' alfalfa. They found a relatively greater variance of GCA to SCA for these characters.

Davis and Gartner (1966) evaluated an eight-clone diallel cross population of alfalfa and reported that the GCA for recovery after cutting, seedling height and plant weight were significant and more important than SCA. Likewise, greater GCA effects were obtained for growth habit and vigor by Carnahan *et al.* (1960), Wilcox and Wilsie (1964), Dudley (1963) and Evans *et al.* (1969). Studies on the gene action (in terms of combining ability) for winterhardiness and stand persistence were comparatively limited. In Western Canada winter-killing is a common phenomenon in an alfalfa stand and the selection for winterhardy strains should be given priority over forage yield. Elling *et al.* (1960) found the GCA variance for winterhardiness was six times that for SCA, although both variances were highly significant. Pearson and Elling (1961) obtained significant SCA for winterhardiness and significant GCA for persistence. Theurer and Elling (1962) showed that GCA was more important than SCA for both winterhardiness and persistence, and that these variances were significant. The above results pointed to the substantial additive gene action for these characters. The selection of desirable genotypes for these traits by means of simple mass selection would be effective.

The photosynthetic rate of the leaves is of interest in a breeding program in which the objective is to increase the yield potential. Theoretically, an increase in the photosynthetic rate of individual leaves can be expected

to improve crop yield. Pearce *et al.* (1969) reported that the high yield of two alfalfa populations might have been a result of high specific leaf weight (SLW) and greater photosynthetic capabilities. Delaney and Dobrenz (1974(a)) showed forage yield of alfalfa to be correlated with photosynthesis of the whole plant. Wide genetic variability for photosynthetic rate has been reported in alfalfa (Pearce *et al.*, 1969; Delaney and Dobrenz, 1974(b); Carlson *et al.*, 1970).

The results of photosynthetic rate studies in alfalfa pointed to two important conclusions: (1) photosynthetic rate, expressed as net photosynthesis (mg CO_2 dm^{-2} hr^{-1}), was found to be positively correlated with specific leaf weight or SLW (defined as leaf dry weight per unit leaf area); (2) different cultivars of alfalfa showed a range of values for net photosynthesis and SLW. Since SLW is an easier character to measure than net photosynthesis, it could be used with advantage as an indicator for the photosynthetic rate of a cultivar.

Leaf (or leaflet) area is also another important selection criterion for increasing forage yield. Appreciable genetic variability for leaflet area has been reported in alfalfa (Barnes *et al.*, 1969; Delaney and Dobrenz, 1974(b)). These workers also showed that both leaflet area and SLW were genetically independent. Cultivars or clones were found that combined larger leaflet area with high values

of SLW. Thus selection for both characters could be considered at the same time.

2. *Association between characters.* The information on the association of characters could be used in two ways: (1) it could be utilized for the early elimination of inferior genotypes; (2) it is also of importance in any plant breeding program when selection is based on two or more characters simultaneously.

Seedling vigor has been successfully used as an early selection criterion for the elimination of plants that are inferior in forage yield. This situation was made possible by the significant positive correlation between these two traits. Burton (1937) found stem length of six-week old alfalfa seedlings gave a good correlation with forage yield. Plants with superior seedling vigor tended to be higher in forage yield. Battle and Pettem (1953) reported that plants selected on the basis of superior seedling vigor showed better survival after transplanting, higher yield and more rapid spring growth in the second year. Carnahan *et al.* (1960) showed that seedling vigor and fall growth habit were positively correlated, and this association was little affected by differences between locations. Further, in this experiment it was found that plants with good seedling vigor tended to be erect in the fall growth while the ones with poorer vigor were generally prostrate.

The interrelationship between spring and fall vigor, recovery after cutting, plant height, growth habit and winter survival in alfalfa has also been investigated by some workers. Heinrichs (1958) found a slower fall recovery of shoot after cutting and a higher level of carbohydrates in the roots to be closely associated with plants that could withstand winter-kill. These associations were negative (r=-0.76) between amount of fall growth and winterhardiness, and was strongly positive (r=+0.78) between level of carbohydrates in the roots with winterhardiness. Similarly, Elling *et al.* (1960) reported a highly significant correlation (r=0.49) between winter-killing and fall growth habit from a diallel combination involving 14 alfalfa clones of diverse origins. In this study, it was also found that the progenies of certain clones made substantial fall growth and suffered little winterkilling. Such results were also obtained by Theurer and Elling (1962) who reported that certain crosses were winterhardy and at the same time could make substantial fall recovery. Busbice and Wilsie (1965) studied the relationship of fall growth, winterhardiness and recovery after cutting in F_2 progenies of 'Vernal' and 'Du Puits' alfalfa. They concluded that the positive correlations between fall growth, spring recovery and yield, and between fall growth and recovery after cutting, were suggestive of recombination of genes for fall growth, winterhardiness and rapid recovery after cutting. They also suggested that simultaneous selection for these

three traits would be effective.

Most reports on the association of various morphological and agronomic characters with forage yield in alfalfa have been described using simple correlation coefficients. In some cases this technique is less useful. A simple correlation coefficient between two characters does not necessarily imply a cause-and-effect relationship. Many unknown factors could have influenced the strength of this association. Frakes *et al.* (1961) studied the relationship of plant height, stem length, plant width and stem diameter with forage yield in a population of spaced planted alfalfa. They found that the correlation between these characters with forage yield were significant and positive. However, the results from pathway coefficients gave a different picture. They showed plant width to be direct in its effect on forage yield whereas stem number was primarily indirect in its effect. Furthermore, a large portion of the significant association of height or stem length on forage yield was indirect via the plant width. Liang and Riedl (1964) found positive and significant correlation of forage yield with plant height, number of stems, number of leaves and number of internodes. Also, by the pathway coefficients, they showed that plant height and number of stems had the greatest direct influence on forage yield, while the number of leaves and internodes per tallest stem only had minor effects. The strong correlation of number of leaves and internodes with

forage yield was due to their indirect influence via the plant height and number of stems.

More recently two statistical techniques have proven their value in interpreting the interrelationship between characters. These were the multiple regression and factor analysis. As a technique, the multiple regression analysis could be useful when the main interest is the prediction of the response (or dependent) variable for a set of predictable (or independent) variables. Generally, yield is chosen as the response variable while the other agronomic characters are the predictable variables. This method has been useful in identifying factors influencing yield. Because yield is dependent on a number of factors, fitting all the important factors in the form of a multiple regression equation could explain yield variation. In cereal crops, this technique has been found to be useful in selecting the important factors that affect grain yield (Hsu and Walton, 1971; Walton, 1971; Lee and Kaltsikes, 1973). Factor analysis, which is a multivariate statistical technique, is also useful in explaining the interrelationship among a set of selected variables. Essentially, this method reduces the number of characters into a smaller number of 'factors.' The selection of one character (with the highest factor loading) in each of these 'factors' will in all likelihood preserve most of the information. This method is of importance to a breeder in the initial

choice of the characters to be studied. The selection of one character in each 'factor' would reduce the work involved without limiting the information obtained or the selection advances made. Factor analysis has been used by a number of workers in studying the association of characters in crop plants (Murty *et al.*, 1970; Hsu and Walton, 1971; Walton, 1971; Briggs and Shebeski, 1972; Waddington, 1972; and Lee and Kaltsikes, 1973).

3. *Stability of the single crosses.* An important objective in many plant breeding programs is the selection of genotypes that are consistently high yielding in different locations or years. In practice, however, such an objective was difficult to fulfil. When materials were grown and compared over a series of environments, the relative rankings usually differed - either between locations or years. Such inconsistency in performance was commonly attributed to genotype × environment interactions, and may be present in pure lines, clones, single or double cross hybrids or synthetics.

The concept of selecting for a stable genotype has been suggested as a method for reducing the effect of genotype × environment interactions. Theoretically, such a genotype would be well buffered against change, and could therefore be grown over a wider range of environments. Finlay and Wilkinson (1963) expressed the mean yield of an individual barley variety as a linear function of the environment.

The linear regression coefficient was used to describe the performance of the cultivar, and the environment was denoted by the overall mean of a number of genotypes over locations or years or both. According to this method, a variety with a regression coefficient of one (b=1) would be of average stability. If the regression coefficient was greater than one, the variety would be of below average stability. Likewise, a regression of less than one would describe a variety of above average stability. A high yielding stable variety would, therefore, have a performance above average as well as a regression coefficient of one or less.

Eberhart and Russell (1966) developed this concept further and added a second parameter (deviations from the regression line) as a secondary measure of stability. According to their definition, a stable variety would have a regression coefficient of unity (b=1) and minimum squared deviations ($S_d^2 = 0$) from the regression line. Therefore, a superior stable variety should have these characters as well as being of above average performance. They applied this technique to two sets of diallel crosses in maize (*Zea mays* L.) and found the genetic difference in the F_1s could be determined by the regression coefficients. Further the response of these genotypes in different environments could be measured in terms of the squared deviation values from the regression line. A large number of their F_1s had

unit regression coefficient and near zero squared deviation values. However, a few genotypes have estimates of squared deviation values that were extremely large and thus were not selected as stable genotypes (although they have unit regression coefficients). Eberhart and Russell (1969) used a 10-line diallel of single-cross and double-cross maize hybrids to demonstrate the method. They concluded that double-cross hybrids were more stable than the single-cross hybrids. However, they were able to identify two single-cross hybrids that were as stable as any of the double-cross hybrids. These two single-cross hybrids also out-yielded the commercial varieties. As in their previous publication, Eberhart and Russell (1969) emphasized that the most important stability parameter was the mean square of the deviations from the regression line.

This method of selecting for stable genotypes has also been used by other workers. Eberhart (1971) identified four stable semi-exotic varieties from a regional maize diallel composed of U.S. and semi-exotic lines. Joppa *et al.* (1971) applied this method to select for the stable wheat cultivars from Uniform Regional Nurseries grown at 15 to 20 locations in U.S.A. and Canada. They found that both parameters were under genetic control. Each cultivar had its own characteristic value for b and S_d^2. These studies also substantiated the conclusion of Eberhart and Russell (1966, 1969) showing that S_d^2 was an excellent

indicator of specific genotype × environment interactions. Feaster and Turcotte (1973) used this technique on cotton, while Taliaferro *et al.* (1973) applied the same method to alfalfa. Both workers were able to select stable genotypes.

Other methods of studying stability were demonstrated by Tai (1971) and Hanson (1970). Tai (1971) introduced α and λ in which α was similar to the regression (i.e. b-1) while λ was equivalent to the mean square of deviations. Hanson (1970) defined a stable genotype as one which has minimum possible variability when grown in different environments. This was described by the small regression coefficient (Minimum $\beta = 0$) as well as the small deviation from the regression ($S_d^2 = 0$). Essentially both methods were similar to those developed by Eberhart and Russell (1966).

III. MATERIALS AND METHODS

1. *Materials.* One selection was randomly taken from each of the thirteen cultivars of alfalfa and was used as a parent to produce a diallel cross population. These parents were described by accession numbers and their origins were indicated in parenthesis. The following three diallel crosses were made:

Population A - 7 × 7 diallel cross (F_1s and their reciprocals)

Clone 1 ('Berseem', Sudan)
Clone 2 ('Du Puits', France)
Clone 3 ('Vernal', U.S.)
Clone 4 ('Rambler', Canada)
Clone 5 ('Grimm', U.S.)
Clone 6 ('Beaver', Canada)
Clone 7 ('Roamer', Canada)

Population B - 5 × 5 diallel cross (F_1s and their reciprocals)

Clone 1 ('Berseem', Sudan)
Clone 7 ('Roamer', Canada)
Clone 8 ('Narrangansett', U.S.)
Clone 9 ('Dekalb', U.S.)
Clone 10 ('Alfa', Sweden)

Population C - 6 × 6 diallel cross (F_1s only)

Clone 1 ('Berseem', Sudan)

Clone 2 ('Du Puits', France)

Clone 4 ('Rambler', Canada)

Clone 11 ('U67/126', Sweden)

Clone 12 ('Bendelebener', Germany)

Clone 13 ('Neuga', Germany)

These parents were maintained in the greenhouse. The usual technique for obtaining F_1 seed between any two parental clones involved emasculating the flower, immersing the stigma in 57% alcohol for a few seconds, rinsing in distilled water and applying with pollens from the selected parent. In the present study, this method was found to produce low seed set. An alternative method was used. Flowers at the early bud stage were selected and emasculated. The anthers were removed by means of a vacuum pump equipped with a fine nozzle. The flower was left protected in a pollen bag for two to three days. Pollen from the selected parent was then applied to the stigma by means of a tooth-pick. All the crossings were labelled. A close check on the amount of self-fertility was also carried out. About 50 florets were emasculated at the early bud stage, left protected in pollen bags, and were observed for seed set. For all the parental clones, there was no seed set. Similar check was also undertaken by tripping 500 florets. At no stage had the seed set exceeded 10% for all the

parental clones. On the basis of these results, the present technique for obtaining F_1 seed was carried forward.

Seeds were collected from the matured pods, scarified and germinated on filter papers in a petri dish. The seedlings were then transplanted into 9 cm diameter peat-moss pots that were filled with soil mixture (3 soil: 2 peatmoss : 1 sand). They were maintained in the green-house all through the winter of 1971/72 and were subsequently transplanted to the field at the University Farm (Parkland) in the first week of May 1972. For each population, a randomized block design of four replications was used. In each replication each crossing was represented by a row plot of four plants uniformly spaced at 60 cm apart. Spacing between rows of plants was 120 cm. Check plots of 'Rambler' and 'Roamer' were also planted out. There were two plots per replication for each cultivar.

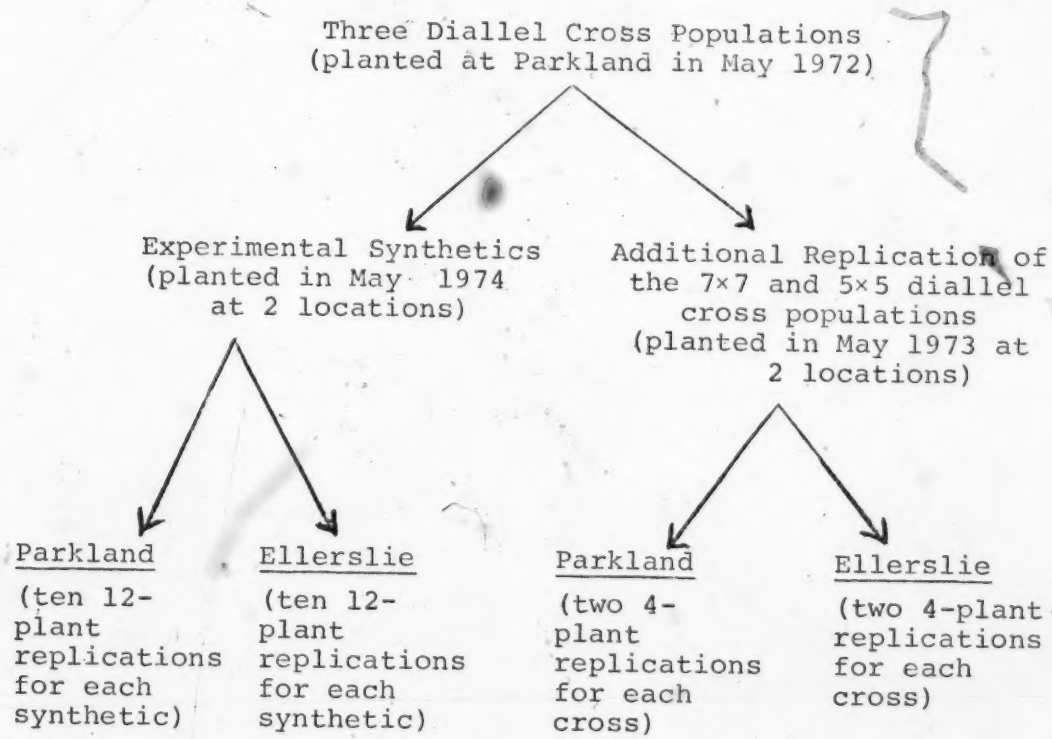
In May 1973, four replications of the 7 × 7 and 5 × 5 diallel cross populations were planted at University Farm (Parkland) and at Ellerslie Research Station (Figure 1). Two replications were maintained at each site. The plants at the University Farm (Parkland) were kept under irrigation in order to create a new environment. These plants were harvested in 1974.

On the basis of the 1972 and 1973 field results from the three diallel cross populations (planted in May 1972),

suitable combination of the parental clones were used to create three experimental synthetic populations (Figure 1). These were as follows:

Experimental synthetic 5 H - selected for higher forage yield and the parents consisted of 5 clones superior in GCA for forage yield. These were clones 4, 5, 6, 7 and 8.

Figure 1. Materials planted at different years and locations in this study



Experimental synthetic 2 H - selected for higher forage yield and the parents consisted of two clones that exhibited superior SCA for forage yield. These were clones 4 and 7.

Experimental synthetic 5 L - selected for lower forage yield and the parents consisted of clones inferior in GCA for forage yield. These were clones 1, 2, 9, 10 and 13.

Seeds for these experimental synthetic populations were obtained by the polycross method. In this process the flowers of the selected parents within each population were tripped at random by means of a tooth-pick, alternating between flowers of different parents. These seeds were scarified and germinated in February 1974. The seeds from 'Rambler' alfalfa were also germinated. These materials were transplanted to the field in the first week of May 1974. Two sites were used - University Farm (Parkland) and Ellerslie Research Station. At each location a randomized block of ten replications were planted. Each plot consisted of 12 plants. The spacing was similar to that used for the diallel cross populations. All plants were harvested in 1974 (July and September harvests) and the dry weight for each population was determined for each location.

2. *Methods*. The following characters, grouped under two headings, were measured (single plant basis) on the

three diallel cross populations that were planted out in the field in May 1972.

Agronomic characters

a) forage yield

b) vigor

c) frost tolerance and winter survival

d) growth habit

e) plant height

f) days to flower (1st and 10th flower)

Morphological characters

g) leaflet area and specific leaf weight.

All the above characters were studied in the 7 × 7 diallel cross population. The agronomic characters (numbers a - f) were also studied in the 5 × 5 diallel cross. In the case of the 6 × 6 diallel cross, where extensive winter-killing occurred, only the forage yield, vigor, frost tolerance and winter survival were investigated.

When the materials were kept in the greenhouse in 1971/72, forage yield and plant height were also recorded. Both characters were measured on a 4-plant plot basis (one plant per pot) in each replication, and this order of replication was maintained when the materials were planted out in the field. Forage yield was recorded in grams of dry weight while plant height (or seedling height) was measured in centimeters.

In the field, forage yield was recorded in grams of dry matter per plant and was obtained from the harvests of 1972 (one harvest - July), 1973 (two harvests - July and early September) and 1974 (two harvests). Plant height was measured in centimeters per plant for the natural height of the plant at 60 days from the date of transplanting (i.e. in early July). This was repeated in the first week of July in 1973. Vigor, growth habit and frost tolerance were visually scored from 1 to 9, with 9 = excellent vigor, erect growth habit or good frost tolerance, and 1 = poor vigor, prostrate growth or poor frost tolerance. Both vigor and growth habit were recorded early in July 1972, and were repeated about the same time in 1973. However, the growth habit in 1973 was based on the ratio of natural height to the width of the crown. This was then transformed to a scale that was comparable to the growth habit obtained in 1972 by dividing by the largest ratio and multiplying by 9. Additional measurements on vigor were taken on regrowth in September of 1973 to mark the fall vigor. Frost tolerance was recorded on regrowth in late September in 1972 and 1973. Both measurements were taken after a severe frost.

Days to flower (1st and 10th flower) were recorded from the first day of June each year. The appearance of the first (and tenth) flower were noted on each plant in 1972 and 1973. Winter survival was counted as 0 or 1, with

0 = winter killed and 1 = winter survived. Observations were taken in the early part of the growing season in 1973 and 1974.

Samples for the study of leaflet areas and SLW were taken from the 7 × 7 diallel cross population after the first harvest in 1974. The regrowth at this stage was very uniform. The first sample (Stage I) was taken in early August while the second sample (Stage II) was collected three weeks later. In Stage I two shoots were sampled from each plant at the early bud stage. All the unfolded leaves were cut off from the petioles. They were counted and their total leaf area was determined by an automatic leaf area meter (Hayashi-Denko - Model AAM-5) with an accuracy of ±1%. Leaflet area was calculated as the total leaf area divided by three times the number of leaves. These samples were dried at 80°C in a forced-draft oven for 24 hours and their dry weight was recorded. SLW was calculated as the ratio of the dry weight of leaves to the total leaf area. The experiment was repeated for Stage II when the shoots were at a late bloom stage.

For materials that were planted in the field in 1973 and 1974, only forage yield (grams of dry matter per plot) were determined (Figure 1). These plants consisted of: (1) an additional four replications of the 7 × 7 and 5 × 5 diallel cross populations (planted in 1973) for the purpose of studying stability of single crosses; (2) twenty

replications of experimental synthetics (planted in 1974) for comparing the performance of polycrossed populations. These materials were harvested in July and September 1974.

3. *Statistical analysis.* Analyses of data were carried out in terms of: (i) combining ability; (ii) association of characters; (iii) stability of the single crosses.

(i) *Combining ability.* The mean value of each plot was used in the analyses of variance for all characters. The mean squares of the single crosses, where significant, were partitioned into general combining ability (GCA), specific combining ability (SCA) and reciprocal effects (RE) as outlined by Griffing (1956). The mathematical model for the combining ability effects is as follows:

$$Y_{ijk} = u + g_i + g_j + s_{ij} + r_{ij} + e_{ijk}$$

where u is the population mean effect, g_i (or g_j) is the GCA effect for the i^{th} (or j^{th}) parents, s_{ij} is the SCA effect for the cross between i^{th} and j^{th} parents such that $s_{ij} = s_{ji}$, r_{ij} is the reciprocal effect and e_{ijk} is the residual error associated with the ijk^{th} plot. The restriction imposed on this model was that the sum of g_i or s_{ij} effects would be equal to zero. For diallel cross population 'A' and 'B' where F_1s and their reciprocals were involved Method 3, Model 1 was used. For the population 'C' where only F_1s were involved Method 4, Model 1 was used.

The expectation of mean squares in both analyses were as follows:

Method 3, Model I

Source of variation	df	Expectation of mean squares
Replications	(r-1)	
Single crosses	(s-1)	
GCA	(p-1)	$\sigma^2 + 2ry(p-2)(\frac{1}{p-1})\ \phi_G$
SCA	p(p-3)/2	$\sigma^2 + 2ry(\frac{2}{p(p-3)})\ \phi_S$
RE	p(p-1)/2	$\sigma^2 + 2ry(\frac{2}{p(p-1)})\ \phi_R$
Error	(r-1)(s-1)	σ^2

Method 4, Model I

Source of variation	df	Expectation of mean squares
Replications	(r-1)	
Single crosses	(s-1)	
GCA	(p-1)	$\sigma^2 + ry(p-2)(\frac{1}{p-1})\ \phi_G$
SCA	p(p-3)/2	$\sigma^2 + ry(\frac{2}{p(p-3)})\ \phi_S$
Error	(r-1)(s-1)	σ^2

where σ^2 was the sampling variance associated with the plot; r = replications; y = environments; s = number of single crosses; p = number of parents in the diallel cross. The statistics ϕ_G, ϕ_S and ϕ_R were the sum of squares for the GCA, SCA and RE respectively.

The results for each environment, or environments combined, were analyzed with replications and single crosses treated as main factors. Since the spring and fall environments were different, the results obtained within a growing season were treated as environments. In this respect spring and fall vigor were treated as separate measures of vigor. Likewise the first and second harvest in a year were treated as forage yield in two environments.

Where the results of mean squares for GCA were significant, estimates of GCA effects were calculated. Similarly, where SCA or reciprocal mean squares were significant, the SCA effects or reciprocal effects were calculated.

(ii) *Association of characters*. Simple correlations between characters, or of the same character between environments, were calculated with the information from the plot means. In these analyses only the results from the 7 × 7 diallel cross population was used since poorer winter survival in the other two diallels would affect the final conclusion. Genotypic correlations between characters that were measured over two environments were calculated based on data from the F_1 means. For this study, the results from the 7 × 7 diallel cross and the 5 × 5 diallel cross populations were presented. The expectations of mean squares in both cases were as follows:

Source of variation	df	Expectation of mean squares
Environments (Env.)	(y-1)	
Replicates in Env.	y(r-1)	
Single crosses	(s-1)	$\sigma^2 + r\gamma\sigma^2_s$
Single crosses × Env.	(s-1)(y-1)	$\sigma^2 + r\sigma^2_{ys}$
Error	y(s-1)(r-1)	σ^2

where σ^2 = sampling error due to plot; σ^2_{ys} = single crosses × environment interaction variance; σ^2_s = genotypic variance among single crosses; r = replications; y = environments or years; and s = number of single crosses.

The above expectation of mean squares were applied to either the variance of each character or to the covariance between any two characters. Genotypic correlations (r_g) were calculated from these variance and covariance estimates.

$$r_g = \sigma_{g_{12}} / \sqrt{(\sigma^2_{g_1})(\sigma^2_{g_2})}$$

where $\sigma_{g_{12}}$ is the genotypic covariance between characters 1 and 2; $\sigma^2_{g_1}$ and $\sigma^2_{g_2}$ are the genotypic variances of characters 1 and 2 respectively.

Stepwise multiple regression equations were computed with information from plot means of the 7 × 7 diallel cross populations. The detail of this technique was set out by Draper and Smith (1967). The multiple regression

and the multiple coefficient of determination were obtained by adding one independent variable at a time according to their relative importance in determining the response variable (forage yield). Termination of the analysis occurred when the introduction of a new independent variable resulted in a change of less than 1% of variance of the response variable. Two sets of results were regressed on the forage yield of July 1973. The first set consisted of independent variables studied in the greenhouse (i.e. plant height and forage yield) and in the field in 1972. The second set was data from 1973 and the morphological characters recorded in 1974. Forage yield of 1974 was excluded since the objective was to work out the relative importance of other agronomic characters in relation to forage yield of 1973 (July). A factor analysis was carried out for all the above characters. In this technique the measured association of variables or characters, usually presented as correlation coefficients, were replaced by a set of 'factors' which are mutually independent of one another. The calculated value (i.e. factor loading) described the maximum correlation between the variable and the factor. This procedure involved the use of varimax rotation (Harman, 1967). The criterion used to determine the number of factors to be retained was an eigen value of ≥ 0.20. The mathematical description of this technique can be found in Cattell (1965).

(iii) *Stability of the single crosses.* The forage yields of the single crosses from the 7-clone and 5-clone diallels were used in this study. A harvest at each location or year was considered as a single environment since changes in ranking among the genotypes were observed within a year. The results from the year of establishment were left out in all cases. Thus, there were eight environments - six from the University Farm (Parkland) and two from Ellerslie Research Station. Of the six environments at the University Farm (Parkland), four were from materials planted in 1972, while two were from those planted in 1973 and maintained under irrigation. The forage yield was calculated as the average of F_1s and their reciprocals in each replication.

The stability of the single crosses over the environments was estimated by the regression method that was outlined by Eberhart and Russell (1966). The two parameters for stability are described by the model:

$$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$$

where Y_{ij} is the F_1 mean for the i^{th} F_1 at the j^{th} environment, μ_i is the mean of the i^{th} over all the environments, β_i is the regression coefficient that measures the response of the i^{th} F_1 at the j^{th} environment, and I_j is the environmental index obtained as the mean of all the F_1s at the j^{th} environment minus the grand mean.

The calculation of sums of squares, and estimates for

the regression and squared deviation values of single crosses were carried out in the manner set out by Eberhart and Russell (1966).

IV. RESULTS

Experimental results were presented in the following order: (1) combining ability; (2) association of characters; (3) experimental synthetics, and (4) stability of single crosses.

1. *Combining ability.* Analyses of variance were carried out for all the studied characters in each of the three diallel cross populations of alfalfa (Tables 1-3). With the exception of one character (specific leaf weight at Stage II) all the characters displayed significant differences in the single crosses. The mean squares for replications were generally larger than the mean squares for genotypes in most of the characters. In such cases, replication differences were appreciable (Appendix: Tables V-1, V-2 and V-3).

The mean squares of single crosses, where significant, were partitioned into general combining ability (GCA), specific combining ability (SCA) and reciprocal effects (RE). The results for the three diallel cross populations were reviewed in the following order: (a) forage yield; (b) vigor; (c) frost tolerance and winter survival; (d) growth habit; (e) plant height; (f) days to flower; (g) leaflet area and specific leaf weight.

Table 1. Analyses of variance for characters studied in a 7 × 7 diallel cross population

Characters		Mean squares due to			F-values (genotypes)
		Replications	Genotypes	Error	
	df	3	41	123	
Forage Yield	1972 (July)	2355	439	178	2.5 ***
	1973 (July)	21377	39149	4304	9.3 ***
	1973 (Sept)	675	2476	795	3.1 ***
	1974 (July)	45675	42000	10418	4.0 ***
	1974 (Sept)	651	979	327	3.0 ***
	Combined	21669	33441	4306	7.0 ***
Vigor	1972 (July)	9.93	0.61	0.33	1.8 **
	1973 (July)	2.26	4.24	0.67	6.3 ***
	1973 (Sept)	5.90	3.55	0.36	9.9 ***
	Combined	2.90	1.46	0.62	2.4 ***
Frost Tolerance	1972 (Sept)	1.45	0.58	0.12	4.8 ***
	1973 (Sept)	0.43	1.69	0.18	9.4 ***
	Combined	1.28	1.91	0.16	11.9 ***
Winter Survival	1972-74	0.07	0.21	0.05	5.4 ***
Growth Habit	1972 (July)	0.41	3.92	0.30	13.1 ***
	1973 (July)	0.33	1.59	0.19	8.4 ***
	Combined	0.07	4.69	0.31	15.1 ***
Plant Height	1972 (July)	298	55	16	3.4 ***
	1973 (July)	442	241	59	4.1 ***
	Combined	579	172	41	4.2 ***
Days to Flower	1972 (July)	146	123	22	5.6 ***
	1973 (July)	23	49	13	3.8 ***
	Combined	115	64	30	2.1 **
Leaflet Area	Stage I	0.33	0.33	0.09	3.7 ***
	Stage II	1.01	0.16	0.11	1.5 *
	Combined	1.18	0.34	0.13	2.6 ***
Specific Leaf Weight	Stage I	4.86	0.30	0.17	1.8 **
	Stage II	2.21	0.25	0.22	1.1 n.s.
	Combined	6.38	0.39	0.17	2.2 ***

*, **, *** Significant at the 5%, 1% and 0.1% level respectively

Table 2. Analyses of variance for characters studied in a 5 × 5 diallel cross population

Characters		Mean squares due to			F-values (genotypes)
		Replications	Genotypes	Error	
	df	3	19	57	
Forage Yield	1972 (July)	1037	251	119	2.1 *
	1973 (July)	14660	32433	2101	15.4 ***
	1973 (Sept)	5220	5971	910	6.7 ***
	1974 (July)	6610	30672	10045	3.1 ***
	1974 (Sept)	2581	952	391	2.4 **
	Combined	7014	27440	3156	8.7 ***
Vigor	1972 (July)	1.14	0.20	0.11	1.8 *
	1973 (July)	2.71	3.46	0.38	9.1 ***
	1973 (Sept)	0.52	1.13	0.18	6.3 ***
	Combined	3.15	0.93	0.36	2.6 ***
Frost Tolerance	1972 (Sept)	0.16	0.46	0.08	5.8 ***
	1973 (Sept)	0.32	1.39	0.11	12.6 ***
	Combined	0.44	1.54	0.10	15.4 ***
Winter Survival	1972-74	0.10	4.16	1.06	3.9 ***
Growth Habit	1972 (July)	0.31	3.31	0.22	15.0 ***
	1973 (July)	0.32	2.35	0.43	5.5 ***
	Combined	0.17	4.93	0.31	15.9 ***
Plant Height	1972 (July)	104	25	14	1.8 *
	1973 (July)	78	254	27	9.4 ***
	Combined	142	124	25	5.0 ***
Days to Flowering	1972 (July)	78	121	22	5.5 ***
	1973 (July)	3	42	6	7.0 ***
	Combined	29	106	14	7.6 ***

Table 3. Analyses of variance for characters studied in a 6 × 6 diallel cross population

Characters		Mean squares due to			F-values (genotypes)
		Replications	Genotypes	Error	
	df	3	14	42	
Forage Yield	1972(July)	94	133	34	3.9 ***
	1973(July)	11743	22956	1893	12.1 ***
	1973(Sept)	1484	3022	501	6.0 ***
	1974(July)	12390	40833	4580	8.9 ***
	1974(Sept)	298	763	331	2.3 *
	Combined	8190	19495	1605	12.1 ***
Vigor	1972(July)	0.15	0.36	0.23	1.6 *
	1973(July)	1.81	3.96	0.19	20.8 ***
	1973(Sept)	0.32	1.06	0.18	5.9 ***
	Combined				
Frost Tolerance	1972(Sept)	0.04	0.28	0.07	4.0 ***
	1973(Sept)	0.27	0.65	0.13	5.0 ***
	Combined				
Winter Survival	1972-74	1.62	4.61	1.22	3.8 ***

(a) Forage yield (Tables 4-8)

For forage yield all the mean squares of GCA and most of the mean squares for SCA were significant (Table 4). Generally, GCA was more important than SCA in the different environments (as indicated by the ratio of GCA to SCA). The ratio of GCA to SCA for forage yield was smaller in the year of establishment (July 1972) but was largest in the following year (July 1973). The exception to this was the 6 × 6 diallel cross population. In this population the genetic variance was appreciable in the year of establishment. The smaller ratio of GCA to SCA in the following year could be due to the substantial winter-killing in this population. Only 65% of plants survived; while winter survival for the 7 × 7 diallel cross was 95% and for the 5 × 5 diallel cross was 85%.

Estimates of GCA effects for forage yield in the 7 × 7 diallel cross showed that in the main, large negative GCA effects were obtained in clones 1 and 2, while large positive GCA effects were found in clones 4, 5, 6 and 7 (Table 5). Thus clones 1 and 2 produced lower yielding progenies whereas clones 4, 5, 6 and 7 gave higher yielding progenies. Likewise in the 5 × 5 diallel cross clones 1 and 10 produced lower yielding progenies while clones 7 and 8 gave higher yielding offsprings. In the 6 × 6 diallel cross, progenies from clones 1 and 13 were poor in forage yield whereas progenies from clone 4 were higher yielding. The above

results were generally consistent over the environments. The estimates of SCA effects for forage yield in the three diallel cross populations showed that eleven F_1s were superior in forage yield (positive SCA effects) over the environments (Tables 6 and 7). These crosses were 2 × 4, 2 × 7, 3 × 5, 5 × 6 and 6 × 7 in the 7 × 7 diallel cross; 1 × 10, 7 × 8, 8 × 9 in the 5 × 5 diallel cross; and 1 × 11, 3 × 13 and 4 × 11 in the 6 × 6 diallel cross. The yield of these F_1s were generally higher than their respective population means, and were frequently greater than the check cultivars, 'Rambler' and 'Roamer' (Table 8).

Table 4. Mean squares and F-test values for the combining ability of forage yield in the three diallel cross populations of alfalfa.

Source	df	(July) 1972		(July) 1973		(Sept) 1973		(July) 1974		(Sept) 1974		Combined	
		MS	F	MS	F	MS	F	MS	F	MS	F	MS	F
7X7 diallel cross													
GCA	6	404	2.3*	227562	54.1***	9803	12.1***	197858	18.9***	3600	11.0***	187366	43.5***
SCA	14	297	1.7	7963	1.9*	635	0.8	18383	1.8	697	2.1*	7731	1.8*
RE	21	543	3.1***	6107	1.5	1611	2.0*	13218	1.3	418	1.3	6606	1.5
Error	123	178		4204		795		10418		327		4306	
GCA:SCA		1:1		29:1		15:1		11:1		5:1		24:1	
5X5 diallel cross													
GCA	4	182	1.5	111704	53.1***	12547	13.8***	359350	35.7***	9980	25.5***	86515	27.4***
SCA	5	392	3.3*	4703	2.2	742	0.8	209364	20.8***	6020	15.4***	15632	5.0***
RE	10	208	1.7	12989	6.2***	954	1.0	42958	4.3***	2048	5.2***	9718	3.1***
Error	57	119		2101		910		10045		391		3156	
GCA:SCA		0.5:1		24:1		17:1		2:1		2:1		6:1	
6X6 diallel cross													
GCA	5	302	8.9***	27300	14.4***	1754	3.5**	92941	20.2***	1663	5.0***	32448	20.2***
SCA	9	38	1.0	2054	10.8***	3726	7.4***	11883	2.6*	263	0.8	12298	7.7***
Error	42	34		1893		501		4580		331		1605	
GCA:SCA		8:1		1:1		0.5:1		8:1		6:1		3:1	

Table 5. Estimates of GCA effects for forage yield in three diallel cross populations

Clones	(July) 1972	(July) 1973	(Sept) 1973	(July) 1974	(Sept) 1974	Combined
7 × 7 diallel cross						
1	-3.2	-137.7	-29.3	-111.4	5.5	-55.2
2	-3.2	-63.8	0.4	-64.3	4.2	-25.3
3	4.0	8.5	1.3	-30.1	-7.7	-4.8
4	2.7	82.4	5.9	21.6	-5.5	22.1
5	-3.1	39.6	16.7	56.9	8.8	23.6
6	0.3	26.8	14.5	79.5	8.7	26.0
7	2.5	44.0	-9.5	47.8	-14.0	13.6
SE*	3.8	15.3	9.5	22.8	4.0	6.6
5 × 5 diallel cross						
1	-4.4	-82.5	-18.0	-91.9	-3.3	-38.6
7	1.7	55.5	12.7	49.3	13.1	21.0
8	3.2	83.9	33.0	31.2	-5.3	29.2
9	0.6	-9.2	-5.5	-0.1	5.2	-1.8
10	-1.1	-47.8	-22.2	11.5	-9.7	-9.8
SE*	3.2	13.2	8.7	28.9	5.7	6.9
6 × 6 diallel cross						
1	-1.5	-31.1	-10.3	-119.1	-13.6	-37.2
2	8.1	-24.6	-3.1	34.8	15.9	3.8
4	1.3	83.0	17.5	19.5	-7.3	24.8
11	-1.2	-8.9	-6.6	42.8	5.0	16.3
12	-3.9	7.8	7.6	40.3	2.0	7.7
13	-2.9	-10.6	-5.1	-18.3	-2.0	-7.8
SE*	2.1	15.4	7.9	23.9	6.4	6.7

*SE Standard error of difference between any two GCA effects

Table 6. Estimates of SCA effects for forage yield in a 7X7 diallel cross population.

Crosses	(July) 1972	(July) 1973	(Sept) 1973	(July) 1974	(Sept) 1974	Combined
1X2	9.2	-17.1	4.1	-37.5	-20.8	1.6
1X3	- 7.5	12.9	- 5.4	54.5	- 6.5	6.5
1X4	- 2.7	- 4.2	7.3	- 8.7	5.5	- 0.6
1X5	- 4.0	- 5.8	- 4.3	3.3	5.2	- 1.1
1X6	2.0	23.7	0.7	6.6	10.5	- 0.8
1X7	3.0	-16.3	- 2.3	-18.2	6.1	- 5.6
2X3	1.0	13.4	8.8	19.9	5.3	4.3
2X4	- 6.0	14.5	9.4	46.4	7.4	8.5
2X5	- 7.6	-16.6	- 9.3	-52.3	- 8.4	-14.2
2X6	4.8	-34.1	-16.8	-50.8	4.7	-18.4
2X7	- 1.3	2.2	3.7	74.4	11.9	18.2
3X4	- 2.2	30.9	- 7.0	-34.7	- 1.3	- 2.8
3X5	6.5	26.5	9.0	46.2	7.9	19.2
3X6	1.9	-11.9	0.2	- 3.4	- 0.1	2.1
3X7	0.3	-49.1	- 5.6	-82.5	- 5.3	-29.3
4X5	2.7	-36.6	-10.4	10.0	- 3.3	- 7.5
4X6	2.8	-15.4	1.1	-18.8	- 5.3	- 5.1
4X7	5.4	29.7	- 0.4	5.7	- 3.0	7.5
5X6	- 0.8	11.4	12.5	19.3	- 0.7	8.4
5X7	3.2	2.1	2.4	-26.5	- 0.6	- 4.7
6X7	-10.7	39.8	2.3	47.1	- 9.1	13.9
SE(1*)	5.9	29.0	14.1	28.9	8.1	13.1
SE(2)	5.1	25.1	12.2	25.1	7.6	11.4

SE(1*) = standard error between two effects with one parental line in common

SE(2) = standard error between two effects with no parental line in common

Table 7. Estimates of SCA effects for forage yield in a 5X5 and a 6X6 diallel cross population.

Crosses	(July) 1972	(July) 1973	(Sept) 1973	(July) 1974	(Sept) 1974	Combined
5X5 diallel cross						
1X7	-3.9	5.0	- 6.4	5.2	- 0.4	0.1
1X8	9.9	-27.4	2.2	-85.9	-15.6	-23.4
1X9	-5.2	- 4.6	1.7	26.8	12.3	6.2
1X10	-0.7	27.0	14.8	53.9	3.7	17.1
7X8	-1.6	18.0	- 0.8	96.8	13.6	25.2
7X9	1.4	-15.0	- 6.4	-47.5	- 5.3	-14.6
7X10	4.1	- 8.0	0.3	-54.5	- 7.9	-10.7
8X9	-0.5	24.0	9.4	4.6	- 4.6	6.5
8X10	-7.8	-14.5	-10.5	-15.5	6.6	- 8.3
9X10	4.4	- 4.4	- 4.3	16.1	- 2.4	1.9
SE(1)	5.5	18.7	12.8	40.9	8.1	9.6
SE(2)	3.9	13.2	9.1	28.9	5.7	6.8
6X6 diallel cross						
1X2	3.1	-42.9	-52.4	- 4.5	- 1.9	-19.7
1X4	0.2	-27.9	- 7.0	45.5	1.9	2.5
1X11	-2.3	-10.8	19.9	35.5	7.4	9.9
1X12	-0.1	63.1	39.9	-22.2	1.1	16.4
1X13	-0.9	18.2	- 0.4	-54.3	- 8.4	- 9.1
2X4	3.6	-70.2	-22.9	14.9	- 6.2	-12.2
2X11	-2.9	0.5	28.5	-47.8	- 1.7	- 8.7
2X12	-4.3	9.6	8.5	-24.2	5.2	- 1.0
2X13	0.5	102.9	38.4	61.6	4.6	41.6
4X11	-0.1	119.4	21.7	21.4	8.3	34.1
4X12	-1.7	20.8	- 7.1	5.4	0.7	3.6
4X13	-1.9	-42.1	- 4.7	-87.0	- 4.7	-28.1
11X12	4.6	-61.8	-29.0	-23.9	-14.8	-24.9
11X13	1.5	-31.8	-12.3	64.9	7.7	6.1
12X13	0.8	-47.4	-21.0	14.9	0.8	-10.4
SE(1)	3.6	26.6	13.7	41.4	11.1	11.6
SE(2)	2.9	21.8	11.2	33.8	9.1	9.4

Table 8. Forage yield (grams dry matter/plant) of the eleven single crosses that were consistently high and positive in SCA effects in the diallel crosses.

Crosses	(July) 1972	(July) 1973	(Sept) 1973	(July) 1974	(Sept) 1974	Mean
7X7 diallel cross						
2X4	68	270	216	540	83	234
2X7	73	173	180	586	136	230
3X5	82	348	201	534	92	251
5X6	71	344	218	451	72	231
6X7	67	377	192	553	58	249
Population Mean	74	266	174	378	75	193
5X5 diallel cross						
1X10	42	386	176	450	66	224
7X8	36	335	150	622	88	246
8X9	50	376	165	318	57	193
Population Mean	72	177	133	344	71	159
6X6 diallel cross						
1X11	65	118	123	360	68	117
2X13	75	280	165	380	62	192
4X11	70	340	152	306	75	187
Population Mean	70	169	120	307	69	147
Checks:						
Rambler(n=32)	75	290	120	320	76	176
Roamer(n=64)	50	180	85	280	73	134

(b) Vigor (Tables 9 - 12)

Greatest genetic differences among the F_1s were found for spring vigor (July 1973) and fall vigor (September 1973) (Table 9). The genetic difference for vigor was less marked among the F_1s in the year of establishment (July 1972). Generally for spring and fall vigor the variation due to GCA was greater than SCA. The estimates of GCA effects for these two environments pointed to the existence of genotype × environment interactions (Table 10). This was shown by the lack of consistency in the order of ranking of the GCA effects in these environments. In the 7 × 7 diallel cross, progenies of clones 1 and 2 were poor in spring vigor (negative GCA effects) whereas those of clones 4, 6 and 7 were good in spring vigor (positive GCA effects). In the fall, however, progenies of clones 1 and 2 showed good vigor (positive GCA effects) whereas those of clones 4, 6 and 7 exhibited poor fall vigor (negative GCA effects). In the 5 × 5 diallel cross progenies of clone 1 were poor in spring vigor but good in fall vigor while the reverse were found for progenies of clones 7 and 8. In the 6 × 6 diallel cross the F_1s of clones 1, 2 and 13 gave poor spring vigor but good fall vigor. Likewise the reverse was true for progenies of clone 4. A combined estimate for the GCA effects for vigor therefore gave little useful information since the positive and negative effects for the spring and fall vigor cancelled out.

Estimates of SCA effects for spring and fall vigor showed that eight F_1s combined good spring and fall vigor (Tables 11 and 12). These were crosses 1 × 4, 3 × 5 and 5 × 6 in the 7 × 7 diallel cross; 8 × 10 in the 5 × 5 diallel cross; and 1 × 11, 1 × 13, 2 × 12 and 4 × 11 in the 6 × 6 diallel cross. The reciprocal differences of most of these F_1s in the 7 × 7 and 5 × 5 diallel cross populations were not appreciable.

Table 9. Mean squares and F-test values for the combining ability of vigor in the three diallel cross populations

Source	df	(July) 1972		(July) 1973		(Sept) 1973		Combined	
		MS	F	MS	F	MS	F	MS	F
7×7 diallel cross									
GCA	6	0.48	1.5	23.81	35.5***	19.45	54.2***	3.99	6.2***
SCA	14	0.46	1.4	0.81	1.2	1.34	3.7***	1.05	1.7*
RE	21	0.75	2.3*	1.11	1.7*	0.47	1.3	1.01	1.6*
Error	123	0.33		0.67		0.36		0.62	
GCA:SCA		1:1		29:1		15:1		4:1	
5×5 diallel cross									
GCA	4	0.18	1.5	10.44	27.5***	2.42	13.4***	1.80	5.0***
SCA	5	0.24	2.0	0.57	1.5	0.94	5.2***	0.10	0.3
RE	10	0.14	1.2	2.11	5.6***	0.70	3.9***	0.99	2.8***
Error	57	0.12		0.38		0.18		0.36	
GCA:SCA		1:1		18:1		3:1		18:1	
6×6 diallel cross									
GCA	5	0.59	2.5*	6.20	32.6***	2.32	12.2***	0.50	1.8
SCA	9	0.24	1.0	2.70	14.2***	0.36	1.9	0.29	1.0
Error	42	0.24		0.19		0.19		0.28	
GCA:SCA		2:1		2:1		6:1		2:1	

Table 10. Estimates of GCA effects for vigor in the three diallel cross population

Clones	(July) 1972	(July) 1973	(Sept) 1973	Combined
7×7 diallel cross				
1	-0.13	-1.51	0.97	-0.22
2	0.02	-0.27	0.82	0.19
3	0.10	-0.20	-0.31	-0.14
4	-0.15	0.71	-0.55	0.00
5	-0.01	0.60	0.11	0.25
6	0.14	0.28	-0.11	0.10
7	0.03	0.39	-0.93	-0.18
SE*	0.15	0.20	0.13	0.10
5×5 diallel cross				
1	-0.05	-0.80	0.50	-0.12
7	-0.12	0.53	-0.38	0.02
8	0.10	0.78	-0.09	0.26
9	0.01	-0.05	-0.05	-0.03
10	0.06	-0.46	0.02	-0.13
SE*	0.01	0.18	0.12	0.01
6×6 diallel cross				
1	0.13	-0.71	0.58	0.00
2	0.31	-0.18	0.23	0.18
4	-0.04	1.17	-0.38	0.25
11	-0.11	-0.18	-0.29	-0.25
12	-0.24	-0.08	-0.29	-0.21
13	-0.04	-0.03	0.16	0.03
SE*	0.17	0.16	0.15	0.09

SE* Standard error of difference between any two GCA effects

Table 11. Estimates of SCA and reciprocal effects for spring vigor (July, 1973) and fall vigor (Sept., 1973) in a 7X7 diallel cross.

Crosses	SCA effects		Reciprocal effects	
	(July) 1973	(Sept) 1973	(July) 1973	(Sept) 1973
1X2	0.22	-0.70	-0.40	0.48
1X3	-0.22	-0.17	0.86	-0.08
1X4	0.30	0.57	0.39	0.01
1X5	0.05	-0.09	-0.55	-0.13
1X6	-0.44	-0.17	0.56	0.10
1X7	0.18	0.54	0.00	-0.16
2X3	-0.25	0.24	-0.06	-0.31
2X4	0.00	0.22	0.02	0.13
2X5	0.16	-0.38	0.36	-0.36
2X6	-0.21	0.42	0.23	0.14
2X7	0.08	0.20	-0.47	-0.10
3X4	0.29	0.02	0.09	0.58
3X5	0.21	0.15	0.31	0.16
3X6	0.34	0.00	-0.38	0.16
3X7	-0.87	-0.24	-0.35	-0.03
4X5	-0.91	-0.34	0.49	0.04
4X6	-0.11	-0.14	0.11	-0.18
4X7	0.13	-0.18	-0.04	-0.21
5X6	0.28	0.37	0.18	0.00
5X7	-0.08	0.30	0.26	-0.06
6X7	0.15	-0.62	0.33	0.21
SE(1)	0.36	0.27		
SE(2)	0.32	0.23		

Table 12. Estimates of SCA and reciprocal effects for spring vigor (July, 1973) and fall vigor (Sept., 1973) in a 5X5 and a 6X6 diallel cross populations.

Crosses	SCA effects		Reciprocal effects	
	(July) 1973	(Sept) 1973	(July) 1973	(Sept) 1973
5X5 diallel cross				
1X7	-0.10	0.52	0.75	0.38
1X8	-0.25	-0.05	-0.05	0.03
1X9	0.39	-0.28	0.04	-0.84
1X10	-0.04	-0.20	-0.80	0.03
7X8	0.13	-0.23	0.14	-0.16
7X9	-0.16	-0.11	0.24	-0.03
7X10	0.13	-0.18	-0.26	0.06
8X9	-0.01	0.14	0.99	-0.04
8X10	0.13	0.14	0.00	-0.03
9X10	-0.22	0.25	-0.56	-0.08
SE(1)	0.25	0.17		
SE(2)	0.18	0.12		
6X6 diallel cross				
1X2	-1.40	0.04		
1X4	0.10	-0.06		
1X11	0.21	0.24		
1X12	0.60	-0.21		
1X13	0.40	0.24		
2X4	-0.33	-0.70		
2X11	0.20	0.14		
2X12	0.20	0.34		
2X13	1.20	-0.43		
4X11	1.00	0.24		
4X12	-0.21	0.07		
4X13	-0.43	-0.76		
11X12	-0.32	0.46		
11X13	-0.96	0.09		
12X13	-0.35	0.26		
SE(1)	0.30	0.27		
SE(2)	0.20	0.22		

(c) Frost tolerance and winter survival (Tables 13-16)

Appreciable genetic differences in the F_1s were found for frost tolerance in the fall of 1972 and 1973, and also for winter survival in 1972-74 (Table 13). In general, the GCA variances were larger than SCA or RE variances in the 7 × 7 and 5 × 5 diallel cross populations. In the 6 × 6 diallel cross the variances of GCA were also larger than those of the SCA. Estimates of GCA effects in the 7 × 7 diallel cross indicated that progenies of clones 1 and 2 were poor in frost tolerance and winter survival (negative GCA effects) while those of clones 3, 4 and 7 were good in frost tolerance and winter survival (positive GCA effects) (Table 14). Similar results were found in the 5 × 5 and 6 × 6 diallel cross populations where it was also shown that progenies of clone 1 were poor in both frost tolerance and winter survival whereas those of clones 4 and 7 were good in both characters. In addition to these, progenies of clones 10 and 13 were found to be poor for both characters whereas those of clones 8 and 11 were good. Good consistency in the order of ranking was observed for frost tolerance between the environments. Estimates of SCA effects for frost tolerance showed that nine F_1s were superior in frost tolerance (positive SCA effects) in the fall of 1972 and 1973 (Tables 15 and 16). These were crosses 1 × 2, 1 × 3, 4 × 7, 2 × 5 and 6 × 7 in the 7 × 7 diallel cross; 1 × 9 and 7 × 8 in the 5 × 5 diallel cross;

and 1 × 13 and 4 × 11 in the 6 × 6 diallel cross populations. Reciprocal differences were pronounced in only four of these nine F_1s. These were crosses 1 × 2, 1 × 3 and 2 × 5 in the 7 × 7 diallel cross; and 1 × 9 in the 5 × 5 diallel cross populations.

Table 13. Mean squares and F-test for the combining ability of frost tolerance and winter survival in the three diallel cross populations.

Source	df	Frost tolerance (Sept) 1972 MS	F	(Sept) 1973 MS	F	Combined MS	F	Winter survival 1972-74 MS	F
7X7 diallel cross									
GCA	6	2.27	18.9***	7.98	44.3***	9.12	57.0***	1.19	23.8***
SCA	14	0.47	3.9***	1.03	5.7***	1.18	7.4***	0.06	1.2
RE	21	0.18	1.5	0.33	1.8*	0.34	2.1**	0.02	0.4
Error	123	0.12		0.18		0.16		0.05	
GCA:SCA		5:1		8:1		8:1		20:1	
5X5 diallel cross									
GCA	4	1.69	21.1***	4.59	41.7***	5.90	59.0***	15.52	14.6***
SCA	5	0.15	1.9	0.90	8.2***	0.61	6.1***	1.22	1.1
RE	10	0.13	1.6	0.35	3.2***	0.25	2.5*	1.70	1.6
Error	57	0.08		0.11		0.10		1.06	
GCA:SCA		11:1		5:1		10:1		13:1	
6X6 diallel cross									
GCA	5	0.52	7.4***	0.97	7.5***	0.67	11.2***	11.37	9.3***
SCA	9	0.15	2.1*	0.46	3.5***	0.21	3.5**	0.86	0.7
Error	42	0.07		0.13		0.06		1.22	
GCA:SCA		7:1		2:1		3:1		12:1	

* Significant at the 5% level

** Significant at the 1% level

*** Significant at the 0.1% level

Table 14. Estimates of GCA effects for frost tolerance and winter survival in the three diallel cross population.

Clones	Frost tolerance (Sept) 1972	(Sept) 1973	Combined	Winter survival 1972 - 74
7X7 diallel cross				
1	-0.34	-0.61	-0.48	-1.51
2	-0.20	-0.48	-0.34	-0.20
3	0.00	0.19	0.10	0.30
4	0.30	0.57	0.44	0.51
5	-0.01	0.20	0.10	0.45
6	-0.05	-0.24	-0.15	0.12
7	0.30	0.36	0.33	0.34
SE*	0.08	0.11	0.07	0.22
5X5 diallel cross				
1	-0.30	-0.56	-0.43	-0.83
7	0.33	0.47	0.40	0.54
8	0.08	0.17	0.12	0.92
9	0.14	0.28	0.21	-0.25
10	-0.24	-0.35	-0.29	-0.38
SE*	0.08	0.10	0.06	0.30
6X6 diallel cross				
1	-0.26	-0.38	-0.34	-1.50
2	-0.11	-0.13	-0.12	0.25
4	0.25	0.22	0.24	0.63
11	0.12	0.13	0.13	0.75
12	-0.01	0.26	0.13	0.31
13	0.01	-0.10	-0.05	-0.44
SE*	0.09	0.13	0.09	0.39

SE* Standard error difference between any two GCA effects.

Table 15. Estimates of SCA and reciprocal effects for frost tolerance in a 7X7 diallel cross population.

Crosses	SCA effects			Reciprocal effects		
	(Sept) 1972	(Sept) 1973	Combined	(Sept) 1972	(Sept) 1973	Combined
1X2	0.44	0.32	0.38	0.04	-0.19	-0.08
1X3	0.12	0.22	0.17	0.23	0.31	0.27
1X4	-0.34	-0.40	-0.37	0.19	-0.11	0.04
1X5	0.02	0.10	0.06	-0.06	0.02	-0.02
1X6	0.00	-0.07	-0.03	0.13	-0.04	0.04
1X7	-0.23	-0.18	-0.20	-0.05	-0.16	-0.12
2X3	-0.18	0.04	-0.07	-0.06	0.04	-0.01
2X4	-0.23	0.03	-0.10	0.06	0.03	0.04
2X5	0.04	0.35	0.19	0.20	0.28	0.23
2X6	0.06	-0.55	-0.24	-0.05	-0.06	-0.06
2X7	-0.13	-0.18	-0.16	-0.09	0.04	0.02
3X4	0.14	0.15	0.15	-0.04	-0.13	-0.08
3X5	0.00	-0.10	-0.05	0.11	-0.25	-0.18
3X6	0.04	0.18	0.11	-0.04	0.54	-0.29
3X7	-0.12	-0.49	-0.31	0.00	0.28	0.14
4X5	0.15	-0.04	0.05	-0.09	-0.31	-0.20
4X6	-0.17	-0.13	-0.15	0.10	-0.03	0.04
4X7	0.46	0.39	0.42	0.30	0.04	0.17
5X6	-0.08	-0.10	-0.09	-0.01	-0.19	-0.10
5X7	-0.13	-0.21	-0.17	0.24	0.19	0.21
6X7	0.15	0.67	0.41	-0.34	0.05	-0.14
SE(1)	0.15	0.18	0.12			
SE(2)	0.13	0.16	0.11			

Table 16. Estimates of SCA and reciprocal effects for frost tolerance in a 5X5 and a 6X6 diallel cross population.

	SCA effects			Reciprocal effects		
	(Sept) 1972	(Sept) 1973	Combined	(Sept) 1972	(Sept) 1973	Combined
5X5 diallel cross						
1X7	-0.13	-0.31	-0.22	0.06	-0.20	-0.07
1X8	-0.02	-0.15	-0.09	-0.04	-0.19	-0.11
1X9	0.00	0.37	0.19	0.12	-0.36	-0.11
1X10	0.14	0.10	0.12	-0.06	-0.41	-0.24
7X8	0.16	0.32	0.24	0.23	0.06	0.14
7X9	0.08	-0.26	-0.09	-0.01	-0.21	-0.11
7X10	-0.12	0.25	0.07	0.06	0.03	0.02
8X9	-0.10	0.04	-0.03	0.20	-0.03	0.09
8X10	-0.04	-0.20	-0.12	0.21	0.10	0.16
9X10	0.03	-0.15	-0.07	0.00	0.06	0.03
SE(1)	0.11	0.13	0.09			
SE(2)	0.08	0.09	0.06			
6X6 diallel cross						
1X2	-0.03	-.04	0.02			
1X4	-0.28	-0.06	-0.14			
1X11	0.16	-0.01	0.09			
1X12	-0.01	-0.21	-0.15			
1X13	0.17	0.24	0.16			
2X4	-0.05	-0.10	-0.18			
2X11	-0.10	0.14	0.13			
2X12	-0.01	0.34	-0.18			
2X13	0.19	-0.43	0.20			
4X11	0.21	0.24	0.10			
4X12	0.22	0.07	0.40			
4X13	-0.10	-0.16	-0.18			
11X12	-0.10	-0.46	-0.11			
11X13	-0.17	0.09	-0.21			
12X13	-0.09	0.26	0.04			
SE(1)	0.16	0.26	0.16			
SE(2)	0.13	0.22	0.13			

(d) Growth habit (Tables 17 - 19)

The mean squares for GCA, SCA and RE were generally significant for growth habit (Table 17). In both environments, and also for environments combined, the variance for GCA was larger than those of SCA. This indicated that the gene action for growth habit for both environments were largely additive. Estimates of GCA effects in the 7 × 7 diallel cross showed that progenies of clones 1 and 2 were erect (positive GCA effects) while those of clones 4, 5 and 7 were prostrate (negative GCA effects)(Table 18). In the 5 × 5 diallel cross progenies of clones 1 and 10 were erect whereas those of clones 7, 8 and 9 were prostrate. The above results were consistent in both environments. The methods of measurement in both environments were also different - measured by visual score in 1972 (July) but by meter rule in 1973 (July). Estimates of SCA effects showed that two F_1s were consistently erect in growth habit (positive SCA effects) and five F_1s were consistently prostrate (negative SCA effects)(Table 19). The two erect F_1s were crosses 1 × 7 that appeared in both diallel crosses and 8 × 9 in the 5 × 5 diallel cross. The five prostrate F_1s were crosses 1 × 2, 2 × 5 and 6 × 7 in the 7 × 7 diallel cross; and 1 × 9 and 7 × 8 in the 5 × 5 diallel cross. Three of these F_1s showed appreciable reciprocal differences. These were crosses 2 × 5 and 6 × 7 which showed largest reciprocal effects in 1972 (July) and 1 × 9 that showed largest reciprocal effects in 1973 (July).

Table 17. Mean squares and F-test for combining ability of growth habit in a 7X7 and a 5X5 diallel cross.

Source	df	(July) 1972		(July) 1973		Combined	
		MS	F	MS	F	MS	F
7X7 diallel cross							
GCA	6	19.13	63.7***	8.57	45.1***	25.60	82.6***
SCA	14	2.02	6.7***	0.32	1.7*	1.59	5.1***
RE	21	0.82	2.7***	0.45	2.4**	0.75	2.4***
Error	123	0.30		0.19		0.31	
GCA:SCA		9:1		27:1		16:1	
5X5 diallel cross							
GCA	4	12.25	55.7***	6.36	14.8***	17.49	56.4***
SCA	5	0.89	4.0***	0.52	1.2	1.05	3.4**
RE	10	0.95	4.3***	1.66	3.9***	1.85	6.0***
Error	57	0.22		0.43		0.31	
GCA:SCA		14:1		12:1		17:1	

* Significant of the 5% level

** Significant of the 1% level

*** Significant of the 0.1% level

Table 18. Estimates of GCA effects for growth habit in a 7 X 7 and a 5 X 5 diallel cross.

Clones	(July) 1972	(July) 1973	Combined
7 X 7 diallel cross			
1	1.00	0.75	0.87
2	0.65	0.50	0.57
3	-0.14	-0.02	-0.08
4	-0.69	-0.50	-0.60
5	0.04	-0.29	-0.12
6	0.12	-0.05	0.03
7	-0.97	-0.38	-0.68
SE*	0.16	0.11	0.09
5 X 5 diallel cross			
1	0.62	0.68	0.65
7	-0.95	-0.58	-0.77
8	-0.32	-0.39	-0.36
9	-0.14	-0.03	-0.08
10	0.79	0.33	0.56
SE*	0.14	0.19	0.12

SE* = standard error of difference between any two GCA effects

Table 19. Estimates of SCA and reciprocal effects for growth habit in a 7X7 diallel cross.

Crosses	SCA effects (July) 1972	SCA effects (July) 1973	SCA effects Combined	Reciprocal effects (July) 1972	Reciprocal effects (July) 1973	Reciprocal effects Combined
7X7 diallel cross						
1X2	-0.73	-0.33	-0.53	0.10	0.23	0.16
1X3	-0.29	0.16	-0.06	0.00	-0.28	-0.14
1X4	0.26	-0.30	-0.02	-0.33	-0.09	-0.21
1X5	-0.05	0.04	-0.01	0.00	0.31	0.16
1X6	0.05	0.12	0.09	0.18	-0.56	-0.19
1X7	0.76	0.32	0.54	0.28	0.03	0.15
2X3	0.64	-0.12	0.31	-0.23	0.09	-0.07
2X4	0.11	0.11	0.11	-0.08	0.26	0.09
2X5	-0.67	-0.04	-0.35	-0.91	-0.35	-0.63
2X6	0.34	0.17	0.24	0.04	-0.08	-0.02
2X7	0.32	0.11	0.21	0.31	-0.13	0.09
3X4	-0.04	0.04	0.01	0.11	-0.44	-0.16
3X5	0.14	-0.10	0.02	0.10	-0.23	-0.06
3X6	-0.13	-0.03	-0.08	-0.03	-0.26	-0.14
3X7	-0.32	-0.05	-0.18	0.20	0.26	0.23
4X5	-0.14	0.15	0.01	0.40	0.03	0.21
4X6	0.20	0.10	0.15	0.11	0.04	0.08
4X7	-0.40	-0.09	-0.25	-0.18	-0.09	-0.13
5X6	0.31	-0.06	0.12	0.05	0.01	0.03
5X7	0.40	0.10	0.21	-0.09	-0.01	-0.05
6X7	-0.76	-0.30	-0.53	0.83	0.13	0.48
SE(1)	0.24	0.19	0.14			
SE(2)	0.21	0.17	0.12			
5X5 diallel cross						
1X7	0.37	0.29	0.33	-0.11	-0.79	-0.45
1X8	0.21	0.06	-0.07	0.24	-0.28	-0.02
1X9	-0.11	-0.35	-0.24	-0.41	-0.88	-0.64
1X10	-0.46	0.00	-0.02	-0.09	0.39	0.15
7X8	-0.32	-0.22	-0.27	-0.50	0.01	0.24
7X9	-0.15	0.08	-0.04	0.53	0.08	0.30
7X10	0.10	-0.15	-0.02	-0.29	0.10	-0.09
8X9	0.43	0.14	0.29	-0.31	-0.35	-0.33
8X10	0.10	0.01	0.06	-0.49	-0.40	-0.44
9X10	-0.16	0.13	-0.01	0.04	0.40	0.22
SE(1)	0.19	0.26	0.17			
SE(2)	0.14	0.19	0.12			

Table 20. Mean squares and F-test for the combining ability of plant height in a 7 X 7 and a 5 X 5 diallel cross

Source	df	(July) 1972		(July) 1973		Combined	
		MS	F	MS	F	MS	F
7 X 7 diallel cross							
GCA	6	116	7.3***	1053	17.8***	626	15.3***
SCA	14	31	1.9*	91	1.5	79	1.9*
RE	21	53	3.3***	109	1.8*	104	2.5***
ERROR	123	16		59		41	
GCA:SCA		4:1		12:1		8:1	
5 X 5 diallel cross							
GCA	4	36	2.6*	555	20.6***	258	10.3***
SCA	5	53	3.8**	105	3.9**	62	2.5*
RE	10	6	0.4	209	7.7***	101	4.0***
ERROR	57	14		27		25	
GCA:SCA		1:1		5:1		4:1	

* Significant at the 5% level

** Significant at the 1% level

*** Significant at the 0.1% level

(e) Plant height (Tables 20 - 22)

For both years or environments, the genetic differences in the F_1s were appreciable for plant height (Table 20). Generally, the mean squares of GCA were significant and were larger than the mean squares of SCA or RE. The ratio of GCA to SCA indicated that larger genetic variance for plant height was obtained in the following year (July 1973) as compared to the year of establishment (July 1972). This result was demonstrated in both diallel cross populations for which data were recorded. The estimates of GCA effects in the 7 × 7 diallel cross showed that progenies of clone 1 was shorter in plant height (negative GCA effects) whereas the progenies of clones 3 and 6 were taller (positive GCA effects)(Table 21). Likewise, in the 5 × 5 diallel cross the progenies of clones 1 and 9 were shorter while those of clone 8 were taller. Also a study of the GCA effects for both environments indicated that genotype × environment interactions were appreciable. In the year of establishment progenies of clones 4,5,6, 7 and 8 were shorter but were generally taller in the following year. On the other hand, progenies of clones 2, 3 and 10 were taller but tended to be shorter in the following year.

Estimates of SCA effects showed that five F_1s were tall plants in both environments (Table 22). These were crosses 1 × 2, 3 × 4, 3 × 6 and 5 × 7 in the 7 × 7 diallel cross; and 1 × 10 an the 5 × 5 diallel cross populations. The reciprocal differences of 3 × 4 and 3 × 6 were appreciable.

Table 21. Estimates of GCA effects for plant height in a 7 X 7 and a 5 X 5 diallel cross

Clones	(July) 1972	(July) 1973	Combined
7 X 7 diallel cross			
1	-1.50	-10.90	-6.21
2	1.55	-0.64	0.46
3	2.62	-0.31	1.16
4	-2.23	3.81	0.79
5	-0.23	2.94	1.36
6	0.52	3.74	2.13
7	-0.73	1.34	0.31
SE*	1.17	1.84	1.13
5 X 5 diallel cross			
1	-0.66	-5.79	-3.22
7	-1.62	3.29	0.84
8	-0.08	6.33	3.13
9	0.93	-2.50	-0.79
10	1.43	-1.33	0.04
SE*	1.04	1.50	1.02

SE* = Standard error of difference between any two GCA effects

Table 22. Estimates of SCA and reciprocal effects for plant height in a 7X7 and a 5X5 diallel cross population.

Crosses	SCA effects (July) 1972	SCA effects (July) 1973	SCA effects Combined	Reciprocal effects (July) 1972	Reciprocal effects (July) 1973	Reciprocal effects Combined
7X7 diallel cross						
1X2	3.8	2.5	3.2	1.6	-0.1	0.8
1X3	-1.4	-1.5	-1.5	2.0	7.1	4.6
1X4	-0.3	2.0	0.8	2.0	3.3	2.6
1X5	0.1	0.2	0.1	-0.9	-7.9	-4.4
1X6	-0.9	-4.5	-2.7	3.6	5.5	4.6
1X7	-1.3	1.3	0.0	4.0	0.4	2.2
2X3	-1.6	-3.4	-2.5	-5.4	-1.8	-3.6
2X4	-0.6	1.7	0.6	-0.5	2.3	0.9
2X5	-1.6	1.0	-0.3	-5.0	2.1	-1.4
2X6	1.5	-3.0	-0.7	-0.9	2.8	0.9
2X7	-1.6	1.2	-0.2	-1.3	-3.0	-2.1
3X4	1.0	3.4	2.2	-2.9	-0.8	-1.8
3X5	-0.3	1.3	0.5	-0.4	1.5	0.6
3X6	2.7	4.8	3.8	-3.6	-4.4	-4.6
3X7	-0.4	-4.5	-2.5	3.3	-1.4	0.9
4X5	-0.3	-5.4	-2.8	-1.5	6.0	2.3
4X6	-0.8	0.5	-0.2	-2.0	0.4	-0.8
4X7	1.1	-2.1	-0.5	-0.1	0.1	0.0
5X6	-1.3	0.3	-0.4	0.0	2.8	1.4
5X7	3.4	2.5	3.0	0.5	1.4	0.9
6X7	1.2	1.7	0.2	1.6	5.9	3.8
SE(1)	1.8	3.4	2.5			
SE(2)	1.5	3.0	2.1			
5X5 diallel cross						
1X7	-2.6	3.1	0.2	1.8	6.6	4.2
1X8	2.3	-3.2	-0.4	0.0	-1.4	-0.7
1X9	-1.8	-2.3	-2.0	1.4	-0.3	0.6
1X10	2.1	2.4	2.3	0.0	-0.9	-0.4
7X8	-0.3	2.4	1.1	-0.4	2.4	1.0
7X9	1.7	-2.4	-0.3	-0.1	2.3	1.1
7X10	1.3	-3.1	-0.9	1.0	-5.6	-2.3
8X9	0.8	2.4	1.6	-1.3	9.5	4.1
8X10	-2.8	-1.6	-2.2	-0.5	-1.0	-0.8
9X10	-0.6	2.3	0.6	0.1	-9.0	-4.4
SE(1)	1.5	2.1	1.2			
SE(2)	1.1	1.5	0.8			

(f) Days to flower (Tables 23 - 25)

For the combining ability study, only days to flower (1st flower) was considered. The results of the duration of 1st and 10th flower were similar and their correlations for both years were highly significant (see Association of Characters, Table 32). For days to flower (1st flower), the mean squares for GCA were significant for both environments in the 7 × 7 and 5 × 5 diallel crosses (Table 23). Significant SCA and RE mean squares were also obtained in the year of establishment and in the following year in the 7 × 7 diallel cross. For the 5 × 5 diallel cross, only significant mean squares for SCA and RE were obtained for environments in the following year. Generally, the mean squares of GCA were larger than the SCA. Greater genetic differences in the F_1s were obtained in the year of establishment, since the ratio of GCA to SCA were largest. Estimates of GCA effects showed a general lack of consistency in the ranking of GCA effects for both environments (Table 24). For the 7 × 7 diallel cross progenies of clones 1 and 2 were early flowering (negative GCA effects) while those of clones, 4,5,6 and 7 were late flowering (positive GCA effects) in the year of establishment. In the following year this situation was reversed. Likewise in the 5 × 5 diallel cross, progenies of clones 1 and 8 were early flowering whereas those of clones 7 and 9 were late flowering in the year of establishment. Similarly, in the

following year, the situation was reversed. Estimates of SCA effects showed that four F_1s were consistently early flowering and five F_1s were consistently late flowering (Table 25). These were crosses 3 × 6, 1 × 7 and 5 × 6 in the 7 × 7 diallel cross; and 1 × 7 and 1 × 10 in the 5 × 5 diallel cross for early flowering. The late flowering were crosses 1 × 6, 2 × 5, 4 × 6, 8 × 10 and 9 × 10 in the two diallel cross populations. Of these F_1s only two crosses were large in reciprocal differences. These were 1 × 7 and 2 × 5 in the 7 × 7 diallel cross. Their reciprocal effects were largest in the year of establishment.

Table 23. Mean squares and F-test for combining ability of days to flowering in a 7 X 7 and a 5 X 5 diallel cross

Source	df	(July) 1972 MS	(July) 1972 F	(July) 1973 MS	(July) 1973 F	Combined MS	Combined F
7 X 7 diallel cross							
GCA	6	601	27.3***	144	10.8***	181	6.0***
SCA	14	42	1.9*	33	2.5**	42	1.4
RE	21	41	1.9*	30	2.5**	45	1.5
ERROR	123	22		13		30	
GCA:SCA		15:1		4:1		4:1	
5 X 5 diallel cross							
GCA	4	459	20.9***	91	15.2***	400	28.6***
SCA	5	35	1.6	40	6.7***	49	3.5**
RE	10	29	1.3	23	3.8***	16	1.1
ERROR	57	22		6		14	
GCA:SCA		13:1		2:1		8:1	

* = significant at the 5% level

** = significant at the 1% level

*** = significant at the 0.1% level

Table 24. Estimates of GCA effects for days to flowering in a 7 X 7 and a 5 X 5 diallel cross

Clones	(July) 1972	(July) 1973	Combined
7 X 7 diallel cross			
1	-7.93	1.48	-3.22
2	-2.21	2.84	0.31
3	1.34	1.21	1.28
4	1.97	-1.19	0.39
5	1.82	-2.41	-0.30
6	3.17	-1.39	0.89
7	1.84	-0.54	0.65
SE*	1.22	1.00	0.74
5 X 5 diallel cross			
1	-6.03	1.48	-3.90
7	6.00	-1.90	4.37
8	-0.38	2.14	1.26
9	0.83	-0.41	0.20
10	-0.08	-1.35	-1.03
SE*	1.35	0.71	0.77

SE* = Standard error of difference between any two GCA effects

Table 25. Estimates of SCA and reciprocal effects for days to flowering in a 7X7 and a 5X5 diallel cross population.

Crosses	SCA effects (July) 1972	SCA effects (July) 1973	SCA effects Combined	Reciprocal effects (July) 1972	Reciprocal effects (July) 1973	Reciprocal effects Combined
7X7 diallel cross						
1X2	-4.0	1.6	-1.2	-2.6	0.1	-1.3
1X3	1.5	0.1	0.8	-3.0	-7.0	-5.0
1X4	0.7	-1.5	-0.4	2.3	-1.0	0.6
1X5	-0.2	1.3	0.6	0.0	0.9	0.4
1X6	3.7	1.2	2.5	-1.8	0.0	-0.9
1X7	-1.7	-2.7	-2.2	-4.8	-0.8	-2.8
2X3	-0.1	1.9	0.9	3.6	0.1	1.9
2X4	0.2	-1.9	-0.3	1.3	0.5	0.9
2X5	3.7	0.5	2.1	5.4	-1.9	1.8
2X6	-2.1	-0.9	-1.5	0.3	-2.3	-1.0
2X7	2.2	-2.1	0.0	0.1	2.1	1.1
3X4	-0.9	-0.5	-0.7	3.0	-0.3	1.4
3X5	0.3	-2.9	-1.3	0.5	-2.1	-0.8
3X6	-1.8	-1.5	-1.7	-1.3	-1.8	-1.5
3X7	0.9	3.0	1.9	-0.6	0.1	-0.3
4X5	-0.8	0.1	-0.4	0.5	-1.8	-0.6
4X6	1.6	2.6	2.1	1.8	1.3	1.5
4X7	-0.7	0.1	-0.3	-0.9	-1.8	-1.4
5X6	-1.9	-1.1	-1.5	-0.6	-0.9	-0.8
5X7	-1.1	1.9	0.5	-1.1	1.3	-1.2
6X7	0.4	-0.3	0.1	-1.0	-2.0	-1.5
SE(1)	2.0	1.6	1.1			
SE(2)	1.8	1.4	0.9			
5X5 diallel cross						
1X7	-0.9	-2.1	-2.5	-2.6	1.9	-0.4
1X8	-1.7	-0.4	-1.0	-1.3	-0.6	-0.9
1X9	1.8	-0.9	0.2	-2.9	-0.1	-1.5
1X10	-1.5	-0.8	-1.7	-0.3	0.8	0.3
7X8	0.8	-2.5	-0.9	1.8	-0.1	0.8
7X9	-0.9	-0.9	-0.9	2.3	2.0	2.1
7X10	-1.8	0.0	-0.7	1.5	-1.0	0.3
8X9	-1.3	1.6	0.1	2.8	-4.1	-0.7
8X10	2.2	1.4	1.8	0.6	-1.3	-0.3
9X10	3.0	4.1	4.6	1.1	0.5	0.8
SE(1)	1.9	0.9	1.2			
SE(2)	1.4	0.7	0.8			

(g) Leaflet area and specific leaf weight (Tables 26-28)

For both the leaflet area and specific leaf weight (SLW) the mean squares due to GCA were significant and were more important than SCA or RE (Table 26). This was consistent for both stages of sampling. Greater genetic variability for both characters was obtained at Stage I. Estimates of GCA effects for both characters were presented in Table 27. Progenies of clones 1 and 2 were larger in leaflet area (positive GCA effects) while progenies of clones 4, 6 and 7 were smaller in leaflet area (negative GCA effects). In the case of specific leaf weight (SLW), progenies of clones 1, 2 and 7 were higher in SLW whereas those of clones 4, 5 and 6 were lower in SLW. Estimates of SCA effects indicated four F_1s that combined larger leaflet area with higher SLW. These were crosses 1 × 2, 2 × 3, 3 × 5 and 6 × 7 (Table 28).

Table 26. Mean squares and F-test for the combining ability of leaflet area and specific leaf weight (SLW) in a 7X7 diallel cross.

Source	df	Stage I (August)		Stage II (September)		Combined	
		MS	F	MS	F	MS	F
Leaflet area							
GCA	6	1.47	16.3***	0.38	3.4***	1.15	16.7***
SCA	14	0.11	1.2	0.14	1.3	0.20	2.9***
RE	21	0.14	1.6	0.13	1.1	0.20	2.9***
Error	123	0.09		0.11		0.13	
GCA:SCA		13:1		3:1		6:1	
Specific Leaf Weight (SLW)							
GCA	6	0.66	3.9**	+		0.73	4.1***
SCA	14	0.28	1.6	+		0.45	2.5***
RE	21	0.21	1.2	+		0.24	1.3
Error	123	0.17		0.22		0.23	
GCA:SCA		4:1		-		2:1	

\+ Non-significant mean squares of single crosses for which no partitioning of combining ability was performed.

*, **, *** Significant at the 5%, 1% and 0.1% level respectively

Table 27. Estimates of GCA effects for leaflet area and specific leaf weight (SLW) in a 7 X 7 cross.

Clones	Stage 1 (Aug.)	Stage 2 (Sept.)	Combined
Leaflet area			
1	0.319	0.120	0.169
2	0.108	0.106	0.117
3	0.016	0.099	0.057
4	-0.226	-0.165	-0.145
5	0.075	0.109	0.092
6	-0.087	-0.186	-0.147
7	-0.205	-0.083	-0.144
SE*	0.067	0.073	0.042
Specific Leaf Weight			
1	0.094	-	0.146
2	0.090	-	0.134
3	0.013	-	0.006
4	-0.176	-	-0.235
5	-0.019	-	-0.041
6	-0.114	-	-0.230
7	0.112	-	0.138
SE*	0.094		0.102

SE* = standard error of difference between two GCA effects

Table 28. Estimates of SCA effects for leaflet area (upper diagonal) and specific leaf weight (lower diagonal) for stages I and II combined in a 7X7 diallel cross.

Clones	Clones						
	1	2	3	4	5	6	7
1	-	0.20	-0.15	-0.01	0.00	0.14	-0.18
2	0.59	-	0.24	-0.18	0.05	-0.23	-0.08
3	0.10	0.32	-	-0.32	0.28	-0.05	0.00
4	-0.35	-0.24	0.02	-	0.05	0.13	0.32
5	-0.23	-0.66	0.36	0.30	-	-0.16	-0.23
6	0.05	0.25	-0.18	-0.21	-0.0?	-	0.17
7	-0.17	-0.11	-0.07	-0.01	0.0;	0.35	-

Lower diagonal

SE(1) = 0.20
SE(2) = 0.18

Upper diagonal

SE(1) = 0.19
SE(2) = 0.15

SE(1) = standard error of the difference between any two SCA effects with one parental line in common.

SE(2) = standard error of the difference between any two SCA effects with no parental line in common.

2. *Association of characters.* The results from this study were set out in the order: (a) association of the same character between environments; (b) association between characters; (c) stepwise multiple regression; and (d) factor analysis.

(a) Association of the same character between environments (Tables 29-30)

Forage yield in the greenhouse was positively correlated with field harvest in July 1973 (Table 29). With three exceptions forage yield for different harvest dates in the field were closely correlated with one another. Highest correlations were obtained for forage yield of the two harvest dates within a year. Significant negative correlations were found for spring and fall vigor in 1973 (Table 30). Frost tolerance, growth habit and the plant's height in 1972 and 1973 were positively correlated. However, plant height, measured in the greenhouse, was significantly correlated only with plant height observed in the field in 1972.

Table 29. Simple correlation coefficients for forage yield between environments (n=168).

	(July) 1972	(July) 1973	(Sept) 1973	(July) 1974	(Sept) 1974	Greenhouse (1971/72)
(July) 1972		0.27**	0.17*	0.04	-0.05	0.39**
(July) 1973			0.68**	0.46**	-0.05	-0.02
(Sept) 1973				0.34**	0.18*	0.02
(July) 1974					0.23**	-0.09
(Sept) 1974						0.08
(Greenhouse) 1971/72						

*, ** Significant at the 5% and 1% level respectively.

Table 30. Simple correlation coefficients for the same character between environments (n=168)

	Comparisons	Correlation Coeficients (r)
Vigor	1972 (July) vs 1973 (July)	0.10
	1972 (July) vs 1973 (Sept)	0.21**
	1973 (July) vs 1973 (Sept)	-0.35**
Frost Tolerance	1972 (Sept) vs 1973 (Sept)	0.53**
Growth Habit	1972 (July) vs 1973 (July)	0.65**
Plant Height	1972 (July) vs 1973 (July)	0.21**
	1972 (July) vs 1971 (Greenhouse)	0.34**
	1973 (July) vs 1971 (Greenhouse)	-0.09
Days to Flower (1st flower)	1972 (July) vs 1973 (July)	-0.03
Days to Flower (10th flower)	1972 (July) vs 1973 (July)	-0.13*
Leaflet Area	Stage I vs Stage II	0.39**
Specific Leaf Weight (SLW)	Stage I vs Stage II	0.32**

*, ** Significant at the 5% and 1% level respectively.

(b) Association between characters (Tables 31-33)

Plant height, measured in the greenhouse, was significantly correlated with forage yield (July) in the field (Table 31). Likewise, leaflet area (Stage I) was significantly correlated with forage yield each year. Both plant height and leaflet area (Stage I) were also correlated with vigor and growth habit. Non-significant correlations were obtained for both leaflet area (Stage II) and specific leaf weight with forage yield, vigor and growth habit.

Simple correlation coefficients for various characters studied within a year were set out in Table 32. Generally, the correlation between two characters was similar in 1972 and 1973. In most cases, the strength of this association improved in 1973 showing that closer correlations could be obtained at this stage of growth. Because the days to the first and tenth flower in each year was significantly correlated, the tenth flower was eliminated from the combining ability studies.

Genotypic correlation (r_g) between characters from the data of 7-clone and 5-clone diallels were similar (Table 33). With the exception of days to flower, the genotypic correlations for most characters were significant. Thus, high yielding plants were generally good in vigor and frost tolerance. The significantly positive correlation of plant

height with forage yield, and the negative correlation of growth habit with forage yield, indicated that higher yielding plants were bigger in size but prostrate in growth habit.

Table 31. Simple correlation coefficients for plant height (Greenhouse), forage yield (Greenhouse), leaflet area, specific leaf weight, forage yield (July), vigor and growth habit in a 7X7 diallel cross (n=168).

	Forage yield			Vigor			Growth Habit	
	(July) 1972	(July) 1973	(July) 1974	(July) 1972	(July) 1973	(Sept) 1973	(July) 1972	(July) 1973
Plant Height (Greenhouse)	0.19*	0.22**	0.16*	0.17*	0.16*	0.21**	0.28**	0.04
Forage yield (Greenhouse)	0.39	-0.02	-0.09	-0.04	-0.06	0.08	0.23**	0.12
Leaflet area								
Stage I	0.18*	0.16*	0.25**	0.18*	0.38**	0.38	-0.33**	-0.32**
Stage II	0.16*	0.02	0.05	0.11	0.03	0.06	-0.02	-0.07
Specific leaf weight								
Stage I	0.11	-0.01	-0.09	0.12	-0.01	0.18*	0.02	-0.01
Stage II	0.05	-0.11	0.06	0.05	-0.01	0.01	0.07	-0.01

* Significant at the 5% level.

** Significant at the 1% level.

Table 32. Simple correlation coefficients between agronomic characters studied in each year (n=168).

		Forage Yield (July)	Forage Yield (Sept)	Vigor (July)	Vigor (Sept)	Frost Tolerance	Growth Habit	Plant Height	Days to Flower (1st flower)	Days to Flower (10th flower)	Winter Survival 1972/74
Forage yield (July)	1972		-	0.26**	-	0.26**	0.06	0.61**	-0.25**	-0.35**	0.04
	1973		0.68**	0.89**	-0.49**	0.51**	-0.77**	0.82**	-0.45**	-0.63**	0.16*
Forage yield (Sept)	1972			-	-	-	-	-	-	-	-
	1973			0.69**	0.05	0.09	-0.46**	0.75**	-0.40**	0.57**	0.17**
Vigor (July)	1972				-	-0.09	0.03	0.40**	-0.07	-0.14**	0.11
	1973				-0.35**	0.39**	-0.68**	0.89**	-0.51**	-0.64**	0.25**
Vigor (Sept)	1972					-	-	-	-	-	-
	1973					-0.67**	0.54**	-0.21**	0.15*	0.27**	0.02
Frost Tolerance	1972						-0.68**	0.08	0.17*	0.15*	0.27**
	1973						-0.56**	0.24**	-0.22**	-0.32**	0.32**
Growth Habit	1972							0.18**	-0.40**	-0.44**	-0.05
	1973							-0.47**	0.39**	0.55**	-0.24**
Plant Height	1972								-0.34**	-0.44**	0.18**
	1973								-0.45**	-0.58**	0.18
Days to flower (1st flower)	1972									0.87**	0.14*
	1973									0.78**	-0.26**
Days to flower (10th flower)	1972										0.14*
	1973										-0.21**
Winter Survival 1972/74											

*, ** Significant of the 5% and 1% level respectively.

Table 33. Genotypic correlation (r_g) between characters in 1972 and 1973 from a 7X7 diallel cross (upper diagonal, n=42) and a 5X5 diallel cross (lower diagonal, n=20).

	Forage Yield	Vigor	Frost Tolerance	Growth Habit	Plant Height	Days to Flower (1st)	Days to Flower (10th)
Forage yield	-	0.89**	0.78**	-0.83**	0.73**	0.29	0.05
Vigor	0.90**	-	0.68**	-0.67**	0.89**	0.17	-0.29
Frost Tolerance	0.74**	0.75**	-	-0.89**	0.41	0.30	0.03
Growth Habit	-0.79**	-0.80**	-0.87**	-	-0.49*	-0.44	-0.11
Plant Height	0.85**	0.79**	0.40	-0.52*	-	0.15	0.32
Days to Flower (1st)	0.40	0.29	0.38	-0.40	0.24	-	0.72**
Days to Flower (10th)	0.25	0.05	0.16	-0.20	0.15	0.69**	-

* Significant at the 5% level

** Significant at the 1% level

(c) Stepwise multiple regression (Tables 34-35)

Regressing the results from the greenhouse and field (1972) on forage yield of July 1973 demonstrated that growth habit (X_1), forage yield (X_2), days to flower - 1st flower (X_3) and frost tolerance (X_4) were the most important predictors of forage yield for July 1973 (Table 34). Together they accounted for 50% of the variability for forage yield per plot. When all the remaining variables were forced into the regression, only an additional 1% of the total variability was explained. Thus the remaining variables like days to flower, vigor, height and greenhouse measurements, were not important as predictors. Therefore a good estimate for forage yield of July 1973 could be made from a multiple regression:

$$Y = -208.01 - 29.84X_1 + 2.29X_2 + 5.98X_3 + 40.20X_4$$

($R^2 = 0.50$). Likewise for data of 1973 and 1974 (morphological characters only), fitting most of the agronomic characters could explain 91% of the variability for forage yield of July 1973 (Table 35). Since all other characters only accounted for 9% of the total variability, this study clearly indicated that leaflet area, specific leaf weight and days to flower were not important predictors for forage yield. The best multiple regression in this case was:

$$Y = 170.44 + 24.86X_1 - 38.32X_2 + 2.30X_3 - 15.64X_4 + 0.55X_5$$
$$-9.64X_6 + 9.94X_7, \ (R^2 = 0.91),$$

where X_1 = spring vigor, X_2 = growth habit, X_3 = plant height, X_4 = fall vigor, X_5 = forage yield, X_6 = winter survival, and X_7 = frost tolerance.

Table 34. Partial regression coefficients of characters from greenhouse and field (1972) on forage yield of July in 1973 in the order introduced in the stepwise multiple regression (n=168)

	Step 4	Step 9
1. Growth habit (July 1972)	-29.84***	-33.25***
2. Forage yield (July 1972)	2.29***	1.97***
3. Days to flower (1st flower, 1972)	5.98***	8.38***
4. Prost tolerance (Sept. 1972)	40.20**	35.60*
5. Days to flower (10th flower 1972)		- 4.70
6. Forage yield (greenhouse)		2.51
7. Plant height (greenhouse)		- 0.49
8. Vigor (July 1972)		0.69
9. Plant height (July 1972)		28.18
Intercept	-208.01	-168.11
R^2	0.50	0.51

* Significant of the 5% level
** Significant of the 1% level
*** Significant of the 0.1% level

Table 35. Partial regression coefficients of characters from field (1973) and morphological characters in 1974 on forage yield of July 1973 in the orders introduced in the stepwise multiple regression (n=168).

	Step 7	Step 12
1. Spring vigor (July 1973)	24.86***	23.99***
2. Growth habit (July 1973)	-38.32***	-38.16***
3. Plant height (July 1973)	2.30***	3.35***
4. Fall vigor (Sept. 1973)	-15.64***	-16.68***
5. Forage yield Sept. 1973)	0.55***	0.58***
6. Winter survival (1972/74)	- 9.64**	- 8.65*
7. Frost tolerance (Sept. 1973)	9.94*	10.73*
8. Leaflet area (Stage I)		0.83
9. Days to flower (10th flower)		2.12
10. Leaflet area (Stage II)		- 2.57
11. Days to flower (1st flower)		- 0.22
12. Specific leaf weight (Stage II)		- 3.25
Intercept	170.44	135.18
R^2	0.910	0.913

* Significant of the 5% level
** Significant of the 1% level
*** Significant of the 0.1% level

(d) Factor analysis (Tables 36 - 37)

The factor loadings, communalities and percentage variability of each factor in a varimax rotated matrix are presented in Tables 36 and 37. Table 36 consisted of characters measured in the greenhouse (i.e. plant height and forage yield) and in the field during the year of establishment. Table 37 involved characters studied in the following year and included leaflet area and specific leaf weight.

Three common causative influences (factors) were distinguished which could explain the structural inter-relationships for characters measured in the greenhouse and in the field (1972). Together these three factors accounted for 71% of the total variability. Factor 1 was the causative influence for "establishment" and it consisted of days to flower and greenhouse height and yield measurements. This was the most important factor since it accounted for 32% of the total variability. Factor 2 was involved with "survival" and it contained characters such as frost tolerance and growth habit. Together these two characters accounted for 20% of the variability. Factor 3 was the underlying force for "vigor" since it was made up of characters such as vigor, plant height and forage yield. These characters accounted for 19% of the variability.

In the following year, however, the grouping of the

characters into factors changed slightly. Four factors were extracted, and together they accounted for 75% of the total variability. Factor 1 which described "vigor" was most important since it accounted for 34% of the total variability. Factor 2 was concerned with "survival" and it accounted for 19% of the variation. Factor 3 and 4 were equally important and each accounted for 11% of the total variability. Factor 3 involved "solar interception" and contained the two stages of leaflet area. Factor 4 described the two stages of specific leaf weight and appeared to be causative influence for "photosynthetic rate."

Table 36. A factor analysis for characters of greenhouse and field (1972) in a 7X7 diallel cross population of alfalfa (n=168).

	Communalities	Factors 1	2	3
Factor 1: *Establishment*				
Days to flower (1st flower)	0.76	-0.82	0.27	-0.09
Days to flower (10th flower)	0.76	-0.81	0.25	-0.22
Forage yield-Greenhouse	0.58	0.73	0.22	-0.02
Plant height-Greenhouse	0.48	0.66	-0.14	0.17
Factor 2: *Survival*				
Frost tolerance	0.86	0.01	0.93	0.03
Growth habit	0.77	0.42	-0.77	0.04
Factor 3: *Vigor*				
Vigor	0.78	-0.13	-0.18	0.86
Plant height	0.74	0.41	0.08	0.75
Forage yield	0.68	0.44	0.36	0.60
Percentage of total variance	71	32	20	19

Table 37. A factor analysis for characters of 1973 and morphological characters of 1974 in a 7X7 diallel cross population of alfalfa (n=168).

	Communalities	Factors 1	2	3	4
Factor 1: *Vigor*					
Forage yield (Sept)	0.78	0.87	0.14	-0.08	-0.06
Plant height (July)	0.84	0.86	-0.08	-0.30	-0.03
Vigor (July)	0.87	0.86	-0.29	-0.19	-0.05
Days to flower (10th flower)	0.76	-0.81	0.25	-0.22	-0.03
Forage yield (July)	0.90	0.80	-0.45	-0.18	-0.13
Days to flower (1st flower)	0.55	-0.70	0.12	-0.16	-0.14
Factor 2: *Survival*					
Fall vigor (Sept)	0.84	-0.08	0.90	0.11	-0.12
Frost tolerance (Sept)	0.75	0.17	-0.85	-0.05	-0.03
Growth habit 'July)	0.74	-0.57	0.68	0.04	0.10
Factor 3: *Solar Interception*					
Leaflet area (Stage II)	0.73	-0.14	-0.07	0.81	-0.29
Leaflet area (Stage I)	0.74	0.01	0.39	0.74	0.11
Factor 4: *Photosynthetic Rate*					
Specific leaf weight (Stage I)	0.67	-0.01	-0.12	-0.08	0.81
Specific leaf weight (Stage II)	0.60	0.00	0.09	-0.05	0.77
Percentage of total variance	75	34	19	11	11

3. *Experimental synthetics.* The analysis of variance with both locations combined, showed significant mean square values (P=0.001) for the synthetic populations (Table 38). Although the variation due to location was greatest, it did not mask the differences among the synthetic populations. This was shown by the significant synthetics × location interactions (P=0.01). Highly significant mean squares (P=0.001) were obtained when the synthetic populations were compared at each location (Table 39). This showed that the differences were substantial between the synthetic populations at each location.

Forage yield (grams of dry matter/plant) for the synthetic populations at each location, or at locations combined, demonstrated that both experimental synthetics from selected clones (5H and 2H) were significantly higher in forage yield than either 'Rambler' or 5L - which was the experimental synthetic composed of clones inferior in general combining ability (Table 40). The same result was obtained at both locations. However, the data at one location (Parkland) indicated that two-clone synthetic (2H) was significantly higher yielding than the five-clone synthetic (5H).

The F_1 yields (of the selected parents forming 5H, 2H and 5L) showed that plants from parents of 5H and 2H were generally higher yielding than those selected for 5L and also had better winter survival (Table 41).

Table 38. Analysis of variance for forage yield (mean of two harvests) in four populations of synthetics at two locations.

Source	df	MS	F
Replications	9	17.1	0.7
Synthetics +	3	620.3	25.2***
Error (a)	27	24.6	
Locations	1	16782.0	488.1***
Synthetics X Locations	3	145.7	4.3**
Error (b)	37	34.4	

Table 39. Analysis of variance for forage yield in four populations of synthetics at each location.

		Locations			
		Parkland		Ellerslie	
		MS	F	MS	F
Replications	9	47.1	3.6**	43.7	1.3
Synthetics +	3	331.3	25.5***	434.7	12.7***
Error	27	13.0		34.2	

* Significant at the 5% level

** Significant at the 1% level

*** Significant at the 0.1% level

\+ Synthetic populations included Rambler alfalfa

Table 40. Forage yield (grams of dry matter/plant) for synthetic populations at each location, and locations combined, in the year of establishment.

Populations	Locations		
	Parkland	Ellerslie	Combined
5H	30.0b	59.1ab	44.6a
2H	34.2a	62.9a	48.6a
5L	21.0d	56.7b	38.9b
'Rambler'	25.0c	47.4c	36.2b

* Data represents mean of ten 12-plant replications which were averaged over two harvests.
Means within a test followed by the same letter do not differ at the 5% level of significance based on Duncan's Multiple Range Test.

+ 5H = experimented synthetics from five clones that were superior in GCA effects for forage yield.

2H = experimental synthetics from two clones with F_1s that were consistently superior in SCA effect for forage yield.

5L = experimental synthetics from five clones that were inferior in GCA effects for forage yield.

Table 41. Forage yield and winter survival from F_1s evaluated in 1972-74

Mean of F_1s from parents that formed	Forage yield of survived plants (gm. D.M./plant)	Winter Survival (%)	Number of plants
5H	238	98	224
2H	236	100	32
5L	124	35	176
Rambler	176	95	64

4. *Stability of the single crosses* (Tables 42-46)

Analyses of variance for forage yield in the 7-clone and 5-clone diallels showed the mean square values due to single crosses × environment interactions were significant (Table 42). Single crosses × environment interactions for the linear regression coefficients (i.e. Sc × Env (linear)) were also significant (Table 43). Partitioning the mean squares of Sc × Env (linear) interactions into variation due to average performance (General or G) and variation due to F_1s (Specific or S) showed that G × Env (linear) interactions were more important than S × Env (linear) interactions. This indicated that, for both sets of diallels, the differences in regression coefficients were largely due to the additive gene action. The mean squares of S × Env (linear) interactions were significant in the 7-clone diallel. Hence, in the 7-clone diallel there is also evidence that the regression coefficients in the F_1s differed because of non-additive gene action.

The average performance of the clones in the two diallel crosses were presented in Table 44. All the regression coefficients were significantly linear. The deviation mean squares from the regression line were small and non-significant for all the clones. Clone 6 was the most desirable genotype as it exhibited above average performance, regression coefficient close to unity and minimum deviation mean square from regression ($\bar{b}$=1.08,

$\bar{S}_d^2$= 6, $\bar{X}$ = 109% of average). Other genotypes that were stable and above average in performance were clones 4, 5, 7 and 8. In contrast, clone 1 was below average in performance and its deviation mean square was relatively larger. Thus it was not as desirable as the above clones.

There were ten F_1s that were of above average performance in the 7-clone diallel (Table 45). Of these, five F_1s appeared most desirable since their regression coefficients were close to unity and their deviation mean squares were non-significant. These crosses were 3 × 6, 3 × 5, 4 × 5, 4 × 6 and 5 × 7. The cross 3 × 6 was most stable as it has a regression coefficient near unity (b=1.06, S_d^2 = 320, $\bar{X}$ = 110% of average). In contrast, the cross 2 × 7 was considered as relative unstable since its deviation mean square was large and significant (b = 0.78, S_d^2=9892, $\bar{X}$ = 113% of average). Generally, the cross 3 × 6 performed well in high yielding environment while 2 × 7 performed well in low yielding environment.

Although the regression coefficients for all the F_1s in the 5-clone diallel were significantly linear, the large and significant deviation mean squares from the regression made them unsuitable for use as stable genotypes (Table 46). There were seven F_1s that were above average in performance. Of these only two could be considered as desirable since their deviation mean squares were non-significant. These were crosses 7 × 8 and 7 × 9.

Table 42. Analysis of variance for forage in 7-clone and 5-clone diallels that were studied in 8 environments in Edmonton.

Source	7-clone diallel			5-clone diallel		
	df	MS	F	df	MS	F
Environments (Env)	7	440810	525.0***	7	160540	192.3***
Single crosses (Sc)	20	20322	24.2***	9	21263	25.5***
Sc X Env	140	4107	4.9***	63	4136	4.8***
Error	337	860		161	835	

*** Significant at the 0.1% level.

Table 43. Analysis of variance for forage yield in 7-clone and 5-clone diallels that were studied in 8 environments in Edmonton

Source	7-clone diallel			5-clone diallel		
	df	MS	F	df	MS	F
Env (linear)	1	91960		1	75601	
Single crosses (Sc)	20	20322	23.6***	9	21263	25.5***
General (G)	6	61020	71.0***	4	45950	55.0***
Specific (S)	14	2880	3.3***	5	3913	4.6***
Sc X Env (linear)	20	94706	61.1***	9	55332	16.7***
G X Env (linear)	6	263451	170.2***	4	80686	24.4***
S X Env (linear)	14	22386	14.5***	5	991	0.3
Pooled deviations	126	1548	1.8***	60	3302	3.9***
Error	337	860		161	835	

Env = Environments

* Significant at the 5% level

** Significant at the 1% level

*** Significant at the 0.1% level

Table 44. Average clone performance in diallel crosses in Edmonton.

	Forage yield (gm/plant)	$\bar{b}$	$\bar{s}^2_d$
7-clone diallel			
Clone 4	202	1.13***	210
Clone 7	199	1.20***	136
Clone 6	197	1.08***	6
Clone 5	192	1.09***	140
Clone 3	181	0.92***	158
Clone 2	172	0.91***	632
Clone 1	139	0.63***	509
Mean	183	1.00	
5-Clone diallel			
Clone 8	184	1.10***	450
Clone 7	181	1.18***	282
Clone 9	156	1.00***	111
Clone 10	155	1.02***	217
Clone 1	151	0.72***	621
Mean	161	1.00	

*** Significant of the 0.1% level.

Table 45. Regression coefficients (upper diagonal) and mean square of deviation (lower diagonal) for each F_1 of 7-clone diallel over 8 environments in Edmonton.

Clones	Clones						
	1	2	3	4	5	6	7
1	-	0.39	0.63	0.66	0.73	0.73	0.65
2	1274	-	0.67	1.26+	0.75	0.74	0.78+
3	911	259	-	0.96+	1.41+	1.06+	1.67
4	976	3248**	3461**	-	1.26+	1.24+	1.37+
5	1126	686	939	450	-	1.24+	1.19+
6	1698	396	320	910	666	-	1.53+
7	6410**	9892**	1189	2569**	583	309	-

All regression coefficients were significantly linear.

+ Mean forage yield above the average.

** Significant of the 1% level.

Table 46. Regression coefficients (upper diagonal) and mean squares of deviation (lower diagonal) for each F_1 of 5-clone diallel over 8 environments in Edmonton.

Clones	Clones				
	1	7	8	9	10
1	-	0.64+	0.32	0.56	0.48
7	5794**	-	1.39+	0.70+	0.82+
8	4585**	1673	-	0.95+	0.81+
9	2299*	1566	3374**	-	0.76+
10	3989**	2542**	3265**	3927**	-

All regression coefficient were significantly linear.

+ Mean forage yield above the average.

** Significant at the 1% level.

V. DISCUSSION

The various aspects of this study were discussed in the following order: (1) General combining ability of the parental clones; (2) Genetic variability of the characters; (3) Association of agronomic characters; (4) Association of leaflet area and SLW with forage yield; (5) Experimental synthetics; (6) Stability of the single crosses, and (7) General discussion.

(1) *General combining ability of the parental clones.* The thirteen clones were random selections from the thirteen cultivars of alfalfa which were selected as representing a wide range of adaptation and genetic variation. In view of these wide differences the performance of the clones was not dissimilar from their respective cultivars and the genetic differences between the thirteen clones were large for most of the characters studied. In the case of forage yield, progenies of clones 1, 2, 10 and 13 were lower yielding while those of clones 4, 5, 6, 7 and 8 were higher yielding. Data collected from uniformity trials demonstrated that "Du Puits" and "Alfa" performed poorly under dryland condition in Western Canada, while "Rambler", "Grimm", "Beaver" and "Roamer" performed well (Heinrichs, 1969). Demonstration trials conducted in Edmonton (1970/72) showed similar results for the above cultivars (Dr. Walton, unpublished). Further it was found that "Berseem" was very winter susceptible and poor in forage yield while "Narrangansett" was

good in both winter survival and forage yield. Hence the inferior progenies of clone 1 (Berseem selection) and clone 2 (Du Puits selection) were indicative of the genetic make-up of the cultivars from which they were selected. The same kind of association existed for the progenies of clone 4 (Rambler selection), clone 5 (Grimm selection), clone 6 (Beaver selection), clone 7 (Roamber selection) and clone 8 (Narrangansett selection). Such results indicated that past selection for these cultivars has been very effective in relation to their adaptation. The cultivars Rambler, Grimm, Beaver, Roamer and Narrangansett have been selected for their ability to adapt to the colder and drier parts of North America. In the initial stages of breeding these cultivars, *Medicago falcata* L. was used to improve their survival characteristics (Elliott and Bolton, 1970). In contrast to this, Berseem and Du Puits were cultivars produced in Sudan and France respectively and the environments for which they were selected were relatively mild. Both cultivars belonged to the Flemish type and were generally poor in survival and forage yield when tested in Western Canada. A further indication of this clone-cultivar relationship could be obtained for vigor, frost tolerance, winter survival and growth habit. Progenies of clones 1 and 2 were good in fall vigor, but poor in spring vigor, frost tolerance, and winter survival, and erect in growth habit. These characteristics were well represented in both Berseem and Du Puits. Likewise, progenies of clones 4, 7

and 8 were poor in fall vigor, but had good spring vigor, frost tolerance and winter survival, and a prostrate growth habit. These features were commonly observed in Rambler, Roamer and Narrangansett. The similarity of clone-cultivar characters was also demonstrated by the leaflet area. Clones selected from Berseem and Du Puits produced progenies with a larger leaflet area, while those from Rambler, Beaver and Roamer gave progenies with narrow leaves or smaller leaflets. Such differences in leaflet area are well known characteristics of the respective cultivars.

Since the combining abilities of clonal parents resembled their respective cultivars for most characters studied, it could be inferred that the problem of random drift associated with random selections might not be serious in this study. Thus, if the experiment were repeated with another set of random selections from these cultivars, similar results might be obtained.

The existence of a substantial amount of genetic variability in this material presented an ideal situation for studying the gene action for various agronomic characters.

(2) *Genetic variability of the characters.* Almost all characters studied in the three diallel cross populations displayed appreciable genetic variability. For most characters the mean squares for replications were as large, or larger, than the mean squares for single crosses. This

would indicate that the genetic variability have been underestimated. Thus, if the differences between replications were smaller, genetic variability could have been larger. Fertility and moisture could be important factors in influencing differences between replications. Results on forage yield showed that plants performed poorly in Replication 4.

A large part of the genetic variability seems to be influenced by additive gene action since the ratios of GCA to SCA were generally large. Results of this nature are in agreement with those reported by many workers where it was shown that GCA was more important than SCA for various characters (Theurer and Elling, 1964; Wilcox and Wilsie, 1964; Evans *et al.*, 1969). The larger GCA in this study was due primarily to the wide genetic differences of the parental clones. In contrast to this, Singh and Lesins (1971) reported substantially higher SCA in relation to GCA for various agronomic characters in their alfalfa population. In their case the parental clones had been selected for GCA, and this source of variation was therefore smaller than SCA. In view of the presence of a large GCA for each character, it should be possible to form synthetic populations based on the genetic differences of the parental clones. Clones selected on the basis of superior GCA could be used to form multi-clone synthetics, while those that exhibited high SCA could be cloned and used as parents for two-clone synthetics.

In an autotetraploid, the number of genotypes used should be large in order to characterize a population. Dessureaux (1959) pointed out that, in a two gene model, a minimum of 25 genotypes should be used. In the present study, 32 plants or genotypes were used to describe an F_1 in the 7-clone and 5-clone diallels. However, in the 6-clone diallel, only 16 plants were involved in each F_1. Thus, some distortion of the GCA and SCA variances could be expected from using such a small population. Such changes might not be serious since the parental clones were of widely different origin. Thus, the variance of GCA would be larger than the variance of SCA for most characters.

The ratio of GCA to SCA could also be used to determine the relative importance of a character in different environments. This ratio was generally large for forage yield, vigor, growth habit and plant height in the second year under field conditions. Thus selection at this stage would be most effective since the plants were bigger and the correlations between various characters were larger than in the year of establishment. However, for days to flower the ratio was generally larger in the year of establishment. The results of the combining ability and association of characters study showed the information on days to flower, recorded in the year of establishment, was not important for selection. This was because the progenies of certain clones, (especially clones 1, 2 and 10) made rapid growth in response to the

warm weather and therefore came into flower earlier. However, in the following year the spring recovery of these plants were slower with the result that flowering was delayed. Consequently the correlation of days to flower between both years were poor. Also their association with plant height, frost tolerance and winter survival was inconsistent, being significantly positive in one year and significantly negative in another. A factor analysis showed days to flower behaved differently in the two years. In the year of establishment, days to flower was associated with factors that appeared to influence "establishment" and was not associated with factors that influence "vigor". However, in the following year, days to flower was grouped with forage yield, plant height and vigor and appeared to be under the causative influence that determine "vigor." Thus, selection for days to flower could be undertaken in the second year. In contrast, selection for frost tolerance could be carried out in the year of establishment. Progenies of certain clones that were frost tolerant in the first year were also found to be frost tolerant in the following year. The correlation of this character between environments were positive and significant. Lower genetic variability for this trait in the second year was due to substantial winter-killing of the frost susceptible plants in the 5-clone and 6-clone diallels.

In studying vigor in alfalfa, it is imperative that

the environment in which this character was measured be specified. This was due to the marked difference in the spring and fall vigor for certain plants. The results from the three diallel cross populations indicated that progenies of these clones with good spring vigor tended to be poor in the fall vigor. On the other hand, there were also clones that gave progenies which combined poor spring vigor with excellent fall vigor. Such a relationship accounted for the significantly negative correlation of spring and fall vigor in the second year. Generally, those genotypes that were good in spring vigor and poor in fall vigor were found to be more frost tolerant, better in winter survival and higher in forage yield. The development of spring and fall vigor was genetically controlled. Heinrichs (1958) found a slower fall recovery after cutting (or poor fall vigor) and a higher level of carbohydrates in the roots to be closely associated with winter survival. Elling *et al.* (1960) reported that plants which exhibited excellent fall vigor tended to be more susceptible to winter-killing. The results presented by these workers and the data set out here indicated that genotypes undergo physiological adjustment to the fall environment, produce less vegetative growth and so go into winter with better root reserves. It is also possible that as well as being associated with the winter survival, the root reserves of the plants were a factor concerned with the good spring vigor.

Leaflet area and specific leaf weight (SLW) were also appreciable in their genetic variabilities in the 7-clone diallel. The gene action for both characters was largely additive. The greater genetic variability observed at Stage I (early bud) pointed to the value of selection at this stage of growth. It was also observed that at Stage II (late bloom) the variation in leaflet area was substantial within each shoot. Similar results were reported by other workers who showed that the leaflet area of a clone was not constant throughout the growing season (Delaney *et al.*, 1974). However, it was also observed that in spite of these changes in leaflet area, the clonal differences were maintained at various stages of growth (Delaney and Dobrenz, 1974(b)).

Thus growth habit, spring vigor, fall vigor, frost tolerance and plant height appeared to be among some of the most effective predictors of forage yield. With the exception of plant height, these characters were evaluated by the visual score ratings. Wilcox and Wilsie (1964) measured growth habit by dividing the height of the plant by its width. In the present study, such a measure of growth habit was found to be highly correlated to the visual score method. Various workers have used visual score ratings to study growth habit (Kehr and Gardner, 1960),

vigor (Carnahan *et al.*, 1960; Evans *et al.*, 1966; Sriwatanapongse and Wilsie, 1968) and frost tolerance (Hill *et al.*, 1972). Since these characters are important in alfalfa, an objective approach in their evaluation might be useful. Spring and fall vigor in alfalfa could be measured by the width of the crown or height of the shoot. The correlation of these characters with visual score for vigor were generally good. A number of workers have used either width of the crown or plant height to measure vigor (Busbice and Wilsie, 1965; Evans *et al.*, 1966; Hill *et al.*, 1972). Such a method would overcome the differences resulting from the visual score ratings obtained by different persons. In general, where the genetic differences is small, it is important to use the objective method.

A commercial stand of alfalfa is normally grown in competitive conditions established by solid seedlings. However, the results from this study only applies to non-competitive conditions in which spaced plants were used. Such an approach was undertaken since the amount of F_1 seeds were limited. In fact, much work in breeding and genetics were carried out in noncompetitive conditions for this reason. Tysdal and Kiesselbach (1944) found an interaction between genotype and plant spacing for forage yield in alfalfa. Theurer and Elling (1964) reported highly significant genotype × spacing interaction involving

seeded rows and plants on 18-inch centres. Similar results were also obtained by Pearson and Elling (1961), Rumbaugh (1963) and Evans *et al.* (1966). In general, these workers concluded that spaced plantings were of little value in predicting solid seeding yields. Thus the results obtained for various characters in the present study could only be confined to spaced plantings.

(3) *Association of agronomic characters in the F_1s.* Genotypic correlations indicated strong genetic associations between forage yield, vigor, growth habit, plant height and frost tolerance. In general, plants higher in forage yield tended to have excellent spring vigor, prostrate growth habit, were bigger in size and had good frost tolerance. Such genetic association may not necessarily imply linkage between these traits. Indeed, characters like yield, vigor and winterhardiness are regarded as being dependent on a large number of genes situated on many, if not all, of the chromosomes. Thus by selfing the F_1s from divergent parents it would be possible to obtain recombinations of the above characters. The genotypes that are of value would be those that combined high forage yield with good fall vigor, frost tolerance and winterhardiness. Theurer and Elling (1963) demonstrated that genotypes could be obtained in the F_2 with substantial fall growth and little affected by winter-killing (although it was generally recognized that plants with good fall growth habit were more winter susceptible).

Likewise, Busbice and Wilsie (1965) found a number of F_2s that were high in forage yield and at the same time good in fall vigor. Daday (1964) studied the genetic association of fall vigor with winter survival and suggested that the close relationship between poor fall vigor with good winter survival was not due to genetic linkage or pleitrophy but to independent ecotypic selection. This would imply that it would be relatively easy to obtain a substantial number of genotypes at the F_1 stage which would combine the attributes of forage yield, fall vigor, spring vigor, growth habit and winter survival. In the present study, there were nine F_1s that showed good spring and fall vigor. Of these, four F_1s were consistently superior in forage yield over the environments (i.e. 3 × 5, 5 × 6, 1 × 11 and 4 × 11). Also, a number of F_1s from the winter susceptible parents were found to be frost tolerant and good in fall vigor. The above results indicated that it would be possible to initiate a breeding program by using all the F_1s with desirable characters to form a base population. A breeding program using recurrent selection for general combining ability could be undertaken to evaluate the progeny performance of the selected parents. Such a breeding program would be directed towards producing cultivars suitable for use in Western Canada. Thus for hay production, it would be ideal to have a population of alfalfa which combined erect growth habit with good spring and fall vigor, as well as good winter survival, frost tolerance and a high

forage yield.

(4) *Association of leaflet area and SLW with forage yield.* The correlations of leaflet area and specific leaf weight (SLW) with forage yield was generally poor. Only leaflet area at the early bud stage was significantly correlated with forage yield. The partial regression coefficient analysis showed that both leaflet area and SLW were of minor importance in influencing forage yield. Further a factor analysis demonstrated that both characters were independent of each other and were determined by different underlying forces. Leaflet area for the two stages of sampling were grouped in a common factor that appeared to be a causative influence for "solar interception", while both stages of SLW were contained in a factor that appeared to be responsible for "photosynthetic rate." Neither leaflet area nor SLW were associated with the factors for "vigor" which was responsible for forage yield. Carlson *et al.* (1970) pointed out that yield could be increased by selecting for higher photosynthetic activity and appropriate changes in morphology, as well as plant canopy and geometry. However, they also emphasized that a positive relationship between photosynthetic rate and yield has yet to be established. Delaney and Dobrenz (1974(a)) studied the relationship of photosynthesis and yield in alfalfa and concluded that photosynthetic rate was not an effective tool in selecting for higher forage yield. Photosynthetic rate, when expressed in unit leaf area or in unit leaf weight basis,

did not correlate well with forage yield. However, when it was expressed on a unit plant basis (to account for all the leaves), the correlation with yield was highly significant. Such an estimate of photosynthetic rate was of little interest since it would be influenced by leaf numbers. However, photosynthetic rate has been found to be highly correlated with SLW (Delaney *et al.*, 1974; Delaney and Dobrenz, 1974(a)). In this study the lack of a significant correlation of SLW and forage yield might be expected from the results obtained by Delaney and Dobrenz (1974(a)). It might thus be concluded that SLW, as well as leaflet area, were not limiting factors to forage yield in alfalfa. Low SLW and leaflet area in a plant could be compensated for by an increase in the total leaf area per plant. Theoretically, this situation would most likely persist until the optimal leaf area index is attained. Data obtained from other crops also leads to a similar conclusion. Hanson (1970) obtained a negative relationship between net photosynthesis and productivity in juvenile maize. He suggested that selection for yield based on photosynthetic rates, when expressed in unit leaf area, could result in lower yield. Although this study has shown SLW and leaflet area were heritable and could be changed by breeding, the relationship of these characters with forage yield needs to be investigated further.

(5) *Experimental synthetics.* The results from the experimental synthetics indicated that progenies from clones

selected for their superior combining abilities (5H and 2H) performed significantly better than the check 'Rambler.' Further, the superiority of 5H and 2H over 5L at both locations demonstrated that selection has been effective in increasing forage yield. The above results were substantiated by data from 1972-1974 for the three diallel cross populations. The data also showed that the F_1s from parents selected to form 5H and 2H had good winter survival. Because these random selections have shown good winter survival, it could be inferred that 'Rambler', 'Roamer', 'Beaver', 'Grimm' and 'Narrangansett' were sufficiently winterhardy for use as a source of genetic materials in synthesizing a new cultivar. The above cultivars have been selected for their winter survival as well as forage yield (Odland and Skogly, 1953; Bolton *et al.*, 1963; Heinrichs, 1965; Heinrichs, 1967). Thus a program that involved progeny testing would be effective in identifying the suitable clones for synthesizing new cultivars for use in this area.

There was some indication that two-clone synthetics could perform better than five-clone synthetics. This was shown by the results of 2H and 5H in the year of establishment. Theurer and Elling (1964), however, observed that two-clone synthetics were inferior to multi-clone synthetics in advanced generations. On the other hand, Kehr *et al.* (1961) reported that no differences in average performance

of two- and multi-clone synthetics. Theoretically, any two clones (selected on the basis of superior SCA in their F_1) could produce two-clone synthetics that could perform as well as multi-clone synthetics.

The parents for such two-clone synthetics should be highly self-sterile to ensure maximum cross pollination. Because inbreeding depression will eventually be introduced in advanced generation, two-clone synthetics are seldom realized in practice. In corn breeding where it is possible to control the pollination mechanism, higher yields resulted from using any two inbreds that have been identified for their high SCA in the F_1s. However, unlike corn, controlling the pollination mechanism in alfalfa is difficult. The alfalfa flowers are small, bisexual and, to some extent, self-fertile. Bradner and Childers (1968) and Pedersen and Stucker (1969) showed male-sterility could be found in alfalfa. Although hybrid seeds could be obtained by using such male-sterile flowers, seed production by this method remained low. This was partly due to the discriminating habit of the bees since male-sterile plants are not attrative to them.

In the present study, the choice of clones 4 and 7 (selected from 'Rambler' and 'Roamer' respectively) to form two-clone synthetics was largely the outcome of high SCA effects for forage yield in their F_1 in 1972-73. However, there were also eleven F_1s which were high in SCA

effects for forage yield over the environments in 1972-74. Their performance was generally better than the checks 'Rambler' or 'Roamer'. Because the parental clones for some of these F_1s came from the Flemish type ('Alfa', 'Du Puits', 'U67/126' and 'Bendelebener'), such results clearly demonstrated that improvement in forage yield could be obtained by increasing the range of genetic material used. Further, by introducing germ plasm from the Flemish types, it might be possible to improve fall vigor in the materials selected from the Canadian cultivars. This was shown by the higher forage yield (second harvest) and good fall vigor for some of the F_1s from these two sources of genetic materials.

Most cultivars of alfalfa used in Canada are the result of multi-clone synthetics. Generally, at least four parents are required to prevent excessive inbreeding in advanced generation, and more than four would be required when the parents are partly inbred (Busbice *et al.*, 1972). Although multi-clone synthetics are inferior to two-clone synthetics for forage yield in the first generation, multi-clone synthetics often prove superior as the generations advance (Theurer and Elling, 1964; Davis, 1970). Kinman and Sprague (1945) recognized that a close relationship existed between the number of parents, their combining abilities, and yield in advanced generation. Generally, as more parents are included in synthetics, there is less yield

depression in advanced generation. However, with a greater number of parents included it becomes difficult to select parents that combine well with each other. It does appear that the present method of identifying a limited number of clones by diallel cross analysis will be useful. In synthesizing a cultivar of alfalfa, selected parents should be superior in general combining ability as well as being unrelated to one another.

(6) *Stability of the single crosses.* Stability of single crosses in diallel cross populations provides an opportunity for investigating the extent to which the statistic b (regression coefficient) is under genetical control. Eberhart and Russell (1969) demonstrated that genetic differences among lines of corn were reflected by their regression coefficient on the environmental index, and that such differences were largely influenced by additive gene action. There was no evidence of non-additive gene action. In this study, a similar result was obtained in the 5-clone diallel. However, in the 7-clone diallel, both the additive and non-additive gene actions affected the regression coefficient. The importance of non-additive gene action in this diallel cross was due to the large difference in the regression coefficients for progenies of clones 1 and 2 when compared to progenies of clones 4, 5, 6 and 7. The regression coefficients for progenies of clones 4, 5, 6 and 7 were generally higher

since these genotypes could perform better in the higher yielding environment. As in the 5-clone diallel, the additive gene action in the 7-clone diallel was much larger than the non-additive gene action. Such results indicate that the regression coefficient (b), which was used to describe general stability, was under genetical control. Taken together, the two diallel crosses contained five parents (clone 4, 5, 6, 7 and 8) that were generally stable and of above average performance. Their regression coefficients were significantly linear and close to unity, while their respective deviation mean squares were either small or non-significant. Stability of these clones could be attributed to better adaptation since they were selected from cultivars that were bred in Canada.

Taliaferro *et al.* (1973) studied forage yield for 14 cultivars of alfalfa harvested over three years at each of the five locations in Oklahoma. They found significant cultivar × location × year interaction, while cultivar × location and cultivar × year interactions were non-significant. They thus concluded that genotype × environment interaction of this nature was not attributed to either year or location effects. It was due to the unique feature of each environment which could involve factors such as soil moisture, soil fertility, temperature, humidity, biotic factors (animals, pathogens, weeds, etc.) or any other factor that makes up the environment. Thus,

in describing stability, it is important to include specific instability as measured by deviation mean square from regression. Eberhart and Russell (1969) pointed out the value of this parameter and this was later substantiated by Joppa *et al.* (1971) and Taliaferro *et al.* (1973). In this respect the work of Johnson *et al.* (1968) has been the subject of much criticism. They were interested in comparing the general stability of hard red winter wheat over a number of environments, and in doing so, have left out environments where diseases, winter-kill, and other known specific factors which might cause large deviation from regression. In the present study, specific instability (as measured by deviation mean squares) was the sole criterion for eliminating a number of genotypes that were generally stable (regression coefficients close to one) and of above average performance. Since the deviation mean squares for these F_1s were large and significant, they could not be considered stable in the true sense.

The concept of selecting for a stable cultivar for use over a wider range of environments is not new, although the technique for its evaluation was developed only recently. The preferred use of double cross hybrids in corn over single cross hybrids is largely the outcome of its relatively more stable nature (Sprague and Federer, 1951). In alfalfa a possible method of selecting for stable genotypes would be to identify a number of stable

single crosses, and use them as a source of genetic material to form a synthetic population. Such a population would have stability similar to the double cross hybrids. Although this program appears fairly easy, the choice of suitable materials is difficult. This is because the most stable genotypes are seldom the best for a given location. Results from this study showed that the six F_1s that were considered stable were not among those high in SCA effects for forage yield. The value of the stability technique could only be appreciated when a large number of environments are involved. Under such conditions, the most practical way to select for a superior genotype would be its average performance, regression coefficients and deviation from the regression line. In this respect, the selection for a high yielding genotype on the basis of high SCA effects over each and every environment becomes impractical.

It is clear that both the stability and SCA techniques identify different genetic materials. The value of each technique depends on the objective. In this experiment, where only a limited number of environments were involved, the value of SCA should be emphasized.

(7) *General discussion.* In Western Canada, an important consideration in most alfalfa breeding programs is the selection of genotypes from which cultivars could be developed with good winter survival, disease resistance

and forage yield. Very often such a combination is difficult to obtain. The antagonistic nature of survival characteristics and forage yield generally imposed a barrier towards producing a higher yielding cultivar. In the main, plant breeders have placed emphasis on the use of *Medicago falcata* L. as a parent in their search for winterhardiness. Such a priority often excludes the use of materials that are of good forage yield potential but of little value in winter survival and disease resistance. Further, the use of *Medicago falcata* L., whose lack of forage yield is well known, has also limited yields. Because most cultivars produced for the dryland conditions in Western Canada have been developed in this manner, there is a need to investigate whether forage yields have been limited by the use of such a narrow range of genetic material. To do this, it is necessary to introduce a wider range of materials and test for their combining abilities.

Since random selections from cultivars produced in Western Canada gave progenies that were good in spring vigor, frost tolerance, winter survival and forage yield, it could be concluded that such cultivars have not been narrowly selected. This would also indicate that these cultivars are sufficiently winterhardy and could be used as a source of genetic material for further yield advance. The results from the experimental synthetic populations

shows that producing new cultivars by selecting from these materials is possible.

An important character that needs improvement among the cultivars in Western Canada is fall vigor. This, no doubt, results from the selection for winter survival, and is related to the use of *Medicago falcata* L. There exists an association between good spring vigor, better winter survival, frost tolerance and poor fall vigor. Such an association was not due to genetic linkage or pleiotrophy, but was the result of selection. From the three diallel cross populations, there were a number of F_1s that combine good fall vigor with good winter survival, frost tolerance and a high yield. Further, a limited number of F_1s were also found that showed good fall vigor as well as good spring vigor. Therefore, a selection program that includes such F_1s would produce useful genetic stocks which could be used to form cultivars suitable for the growing conditions in Central Alberta.

Sriwatanapongse and Wilsie (1968) reported heterosis in certain inter-varietal crosses between *Medicago sativa* L. and *Medicago falcata* L. They also showed that such inter-varietal crosses were higher yielding than intra-varietal crosses. The present study also indicated a similar trend. Of the eleven F_1s that were high yielding (as identified by their high SCA effects over the environments) a number of these were the result of crossing the

materials of the Flemish type ('Alfa', 'Du Puits', 'U67/126' and 'Bendelebener') with the standard type ('Rambler', 'Roamer', 'Beaver' and 'Narrangansett'). Although a high yielding two-clone experimental synthetic has been developed with materials from the standard types (i.e. clone 4 × clone 7) higher yielding two-clone synthetic could have been produced with the use of inter-varietal crossings.

The techniques of combining ability and stability have been compared with the same set of genetic materials in this study. Although both methods fulfill different objectives, there was indication that GCA and general stability identified the same genetic materials. It is apparent that in as far as additive gene action is appreciable, both GCA and general stability methods fulfill the same purpose. However, where the performance of an F_1 is largely determined by the non-additive gene action, the SCA and specific stability techniques seek out different genetic materials. In a case such as this, a plant breeder should be well advised to define the environments for which a cultivar could be produced. Where differences between environments are small, the SCA estimates could be used with advantage to select for genotypes that exhibit heterosis. However, where environmental differences are large, the specific stability method would be effective in identifying superior stable genetic materials.

VI. SUMMARY AND CONCLUSIONS

1. The combining ability of the randomly selected clones was similar to the performance of cultivars from which they were selected. This aspect was demonstrated for forage yield, spring vigor, frost tolerance, winter survival, growth habit and leaflet area. The superior combining ability of forage yield, vigor and winter survival from clones selected from cultivars bred for use in Western Canada indicated that past selection has been effective in relation to their adaptation.

2. For most characters the genetic variability observed was of the additive gene type. In the case where the ratios of GCA to SCA were large, changes to the characters could be made through selection. Generally, growth habit, spring vigor, fall vigor and frost tolerance were the most useful predictors of forage yield.

3. Regrouping of characters could be obtained in the F_1s showing that the close genetic associations of vigor, yield, growth habit, winter survival and frost tolerance might not be the result of linkage and pleiotrophy, but was the result of selection. Such new combinations of characters (e.g. good spring and fall vigor, or good fall vigor and frost tolerance) would be useful as a source of genetic material for selection.

4. Both leaflet area and specific leaf weight were heritable

and could be changed by selection. However, little importance could be attached to these characters since they did not appear to be limiting factors for forage yield.

5. Because random selections from the cultivars produced under the dryland conditions in Western Canada combined very well for winter survival, spring vigor, frost tolerance and forage yield, it could be concluded that these materials are of potential value for yield advance.

6. Experimental synthetics, selected from clones on the basis of combining abilities, would be useful as future cultivars for Central Alberta.

7. There were eleven F_1s that showed high SCA effects for most environments studied. Some of these F_1s were derived from genetic materials of the Flemish type ('Alfa', 'Du Puits', 'U67/126' and 'Bendelebener'). Their use for two-clone experimental synthetics could also be considered.

8. Both parameters for measuring stability, namely b and S_d^2, are useful in identifying a stable genotype. Generally the statistic b was more useful in picking out stable genotypes, while S_d^2 would be useful for eliminating certain F_1s that were less stable.

9. GCA and general stability studies identified the same set of parental clones. However, the F_1s from SCA and

specific stability studies were different. It was thus concluded that the SCA method would be more useful when the differences between environments were small. Where environmental differences were appreciable, the specific stability method might be more useful.

VII. BIBLIOGRAPHY

BARNES, D.K., R.B. PEARCE, G.E. CARLSON, R. H. HART and C.H. HANSON. 1969. Specific leaf weight differences in alfalfa associated with variety and plant age. Crop Sci. 9: 421-423.

BATTLE, W.R. and F.D. PETTEM. 1953. Seedling selection of alfalfa breeding material. Agron. Abstr. P.7

BOLTON, J.L. 1948. A study of combining ability in alfalfa in relation to certain methods of selection. Sci. Agr. 28: 97-126.

BOLTON, J.L., R.K. DOWNEY and R.W. PEAKE. 1963. Note on Beaver alfalfa. Can. J. Plant Sc. 43: 615-617.

BRADNER, N.R. and W.R. CHILDERS. 1968. Cytoplasmic male-sterility in alfalfa. Can. J. Plant Sc. 48: 111-112.

BRIGGS, K.G. and L.H. SHEBESKI. 1972. An application of factor analysis to some breadmaking quality data. Crop Sci. 12: 44-46.

BURTON, G.W. 1937. The inheritance of various morphological characters in alfalfa and their relation to plant yield in New Jersey. N. Jersey Agr. Exp. Sta. Bull. No. 628.

BUSBICE, T.H. and C.P. WILSIE. 1965. Fall growth, winter-hardiness, recovery after cutting and wilt resistance in F_2 progenies of Vernal × Du Puits alfalfa crosses. Crop Sci. 5: 429-432.

BUSBICE, T.H., R.R. Hill and H.L. CARNAHAN. 1972. Genetic and breeding procedures In "Alfalfa Science and Technology". ASA Publication. Agronomy No. 15: 283-318.

CARLSON, G.E., R.H. HART, C.H. HANSON and R.B. PEARCE. 1970. Overcoming barriers to higher forage yields through breeding for physiological and morphological characters. Int. Grassland Congr., Proc. 11th (Queensland, Aust.) P. 248-241.

CARNAHAN, H.L., A.W. HOVIN, H.O. GRAUMANN, W.R. KERR, R. L. DAVIS, L.S. ELLING and C.H. HANSON. 1960. General vs. specific combining ability in alfalfa for seedling vigor and growth habit in the year of establishment. Agron. J. 52: 511-516.

CATTELL, R.B. 1965. Factor analysis: An introduction to essentials II. The role of factor analysis in research. Biometrics 21: 405-435.

DADAY, H. 1964. Genetic relationship between cold hardiness and growth at low temperatures in *Medicago sativa* L. Heredity 19: 173-179.

DAVIS, R.L. and A. GARTNER. 1966. Effects of self-compatibility on reciprocal differences and combining ability in *Medicago sativa* L. Crop Sci. 6: 179-183.

DAVIS, W.E. 1970. The yield in succeeding generations of experimental Lucerne synthetics based on varying plant numbers. Rep. of Fodder Crops Section of Eucarpia 1970 Lusignan, France.

DELANEY, R.H. and A.K. DOBRENZ. 1974(a). Yield of alfalfa as related to carbon exchange. Agron. J. 66: 498-500.

DELANEY, R.H. and A.K. DOBRENZ. 1974(b). Morphological and anatomical features of alfalfa leaves as related to CO_2 exchange. Crop Sci. 14: 444-447.

DELANEY, R.H., A.K. DOBRENZ and H.T. POOLE. 1974. Seasonal variation in photosynthesis, respiration and growth components of non-dormant alfalfa (*Medicago sativa* L.) Crop Sci. 14: 58-61.

DESSUREAUX, L. 1959. Introduction to the autotetraploid diallel. Can. J. Genet. Cytol. 1: 94-101.

DRAPER, N.R. and H. SMITH. 1967. Applied regression analysis. John Wiley and Sons, Inc., New York.

DUDLEY, J.W. 1963. Effects of accidential selfing on estimates of general and specific combining ability in alfalfa. Crop Sci. 3: 517-521.

DUDLEY, J.W., T.H. BUSBICE and C.S. LEVINGS III. 1969. Estimates of genetic variance in "Cherokee" alfalfa (*Medicago sativa* L.) Crop Sci. 9:228-231.

EBERHART, S.A. 1971. Regional maize diallels with U.S. and semi-exotic varieties. Crop Sci. 11: 911-914.

EBERHART, S.A. and W.S. RUSSELL. 1966. Stability parameters for comparing varieties. Crop Sci. 6: 36-40.

EBERHART, S.A. and W.S. RUSSELL. 1969. Yield and stability for a 10-line diallel of single-cross and double-cross maize hybrids. Crop Sci. 9: 357-361.

ELLING, L.J., C.H. HANSON and H.O. GRAUMANN. 1960. Winter killing in diallel crosses of alfalfa. Alfalfa Improvement Conference Report 17: 19.

ELLIOTT, C.R. and J.L. BOLTON. 1970. Licensed varieties of cultivated grasses and legumes. Canad. Dept. Agr. Publication No. 1405.

EVANS, K.H., R.L. DAVIS and W.E. NYQUIST. 1966. Interaction of plant spacing and combining ability in an eight-clone diallel of *Medicago sativa* L. Crop Sci. 6: 451-454.

FEASTER, C.V. and E.L. TURCOTTE. 1973. Yield stability in double haploids of American Pima Cotton. Crop Sci. 13: 232-233.

FINLAY, K.W. and G.N. WILKINSON. 1963. The analysis of adaptation in a plant breeding programme. Aust. Jour. Agric. Res. 14: 742-754.

FRAKES, R.V., R.L. DAVIS and F.L. PATTERSON. 1961. The breeding behaviour of yield and related variables in alfalfa. II. Associations between characters. Crop Sci. 1: 207-209.

GRIFFING, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci. 9: 463-493.

HANSON, W.D. 1970. Relative and comparative genotypic stability parameters. Theor. Appl. Genet. 40: 226-231.

HANSON, W.D. 1970. Selection of differential productivity among juvenile maize plants: Associated photosynthetic rate and leaf area changes. Crop Sci. 11: 334-339.

HANSON, A.A. and H.L. CARNAHAN. 1956. Breeding perennial forage grasses. USDA Tech. Bull. 1145.

HARMAN, H.H. 1967. Modern factor analysis. Chicago: The University of Chicago Press.

HAYES, H.K. F.R. IMMER and D.C. SMITH. 1955. Methods of Plant Breeding. McGraw-Hill, 2nd Edition.

HEINRICHS, D.H. 1958. Winterhardiness evaluation of alfalfa. Alfalfa Imp. Conf. Rept. 16: 70-75.

HEINRICHS, D.H. 1965. Registration of Rambler alfalfa. Crop Sci. 5: 483.

HEINRICHS, D.H. 1967. Roamer alfalfa. Can. J. Plant Sc. 47: 220-221.

HEINRICHS, D.H. 1969. Alfalfa in Canada. Canada Dept. Agric. Publication No. 1377 (1969).

HILL, R.R., K.T. LEATH and K.E. ZEIDERS. 1972. Combining ability among four-clone alfalfa synthetics. Crop Sci. 12: 627-630.

HSU, P. and P.D. WALTON. 1971. Relationships between yield and its components and structures above the flag leaf node in spring wheat. Crop Sci. 11: 190-193.

JOHNSON, V.A., S.L. SHAFER and J.W. SCHMIDT. 1968. Regression analysis of general adaptation in hard red winter wheat (*Triticum aestivum* L.) Crop Sci. 8: 187-191.

JOPPA, L.R., K.L. LEBSOCK and R.H. BUSCH. 1971. Yield stability of selected spring wheat cultivars (*Triticum aestivum* L. em Thell) in the Uniform Regional Nurseries, 1959 to 1968. Crop Sci. 11: 238-241.

KEHR, W.R. 1961. General and specific combining ability for four agronomic traits in a diallel series among six alfalfa clones. Crop Sci. 1: 53-55.

KEHR, W.R. and C.O. GARDNER. 1960. Genetic variability in Ranger alfalfa. Agron. J. 52: 41-44.

KEHR, W.R., H.O. GRAUMANN, C.C. LOWE and C.O. GARDNER. 1961. Nebraska Agr. Exp. Sta. Bull. 200.

KINMAN, M.L. and G.F. SPRAGUE. 1945. Relation between number of parental lines and theoretical performance of synthetic varieties of corn. J. Amer. Soc. Agron. 37: 341-351.

LEE, J. and P.J. [illegible]TSIKES. 1973. Multivariate statist[illegible]l analysis of grain yield and agronomic characte[illegible]s in durum wheat. Theor. and Applied Genet. 43: 226-231.

LIANG, G.H.L. and W.A. RIEDL. 1964. Agronomic traits influencing forage and seed yield in alfalfa. Crop Sci. 4: 394-396.

MURTY, B.R., V. ARUNACHALAM and O.P. JAIN. 1970. Factor analysis in relation to breeding system. Genetica 41: 179-189.

ODLAND, T.E. and C.R. SKOGLEY. 1953. The origin of Narrangansett alfalfa. Agron. J. 45: 243-245.

PEARCE, R.B., G.E. CARLSON, D.K. BARNES, R.H. HART and C.H. HANSON. 1969. Specific leaf weight and photosynthesis in alfalfa. Crop Sci. 9: 423-426.

PEARSON, L.C. and L.S. ELLING. 1961. Predicting synthetic varietal performance in alfalfa from clonal cross data. Crop Sci. 1: 263-266.

PEDERSEN, M.W. and R.E. STUCKER. 1969. Evidence of male-sterility in alfalfa. Crop Sci. 9: 767-770.

ROJAS, B.A. and G.F. SPRAGUE. 1952. A comparison of variance components in corn yield trials: III. General and specific combining ability and their interaction with locations and years. Agron. J. 44: 462-466.

SINGH, S.M. and K. LESINS. 1971. Quantitative genetics nature of vegetative growth in alfalfa. Can. J. Genet. Cytol. 13: 75-80.

SPRAGUE, G.F. and W.T. FEDERER. 1951. A comparison of variance components in corn yield trials. II. Error, year × variety, location × variety and variety components. Agron. J. 43: 535-541.

SPRAGUE, G.F. and L.A. TATUM. 1942. General vs. specific combining ability in single crosses of corn. J. Amer. Soc. Agron. 34: 923-932.

SRIWATANAPONGSE, S. and C.P. WILSIE. 1968. Intra- and Intervariety crosses of *Medicago sativa* L. and *Medicago falcata* L. Crop Sci. 8: 465-466.

TALIAFERRO, C.M., C.E. DENMAN, E.D. MORRISON and D. HOBERT. 1973. Cultivar-environment interaction study of alfalfa yields in Oklahoma. Crop Sci. 13: 619-622.

TAI, G.C.C. 1971. Genotypic stability analysis and its application to Potato Regional Trials. Crop Sci. 11: 184-190.

THEURER, J.C. and L.J. ELLING. 1962. Comparative performance of diallel crosses and related second generation synthetics of alfalfa. II. Winter-hardiness and persistence. Crop Sci. 2: 245-248.

THEURER, J.C. and L.J. ELLING. 1963. Comparative performance of diallel crosses and related second-generation synthetics of alfalfa *Medicago sativa* L. Crop Sci. 3: 25-28.

THEURER, J.C. and L.J. ELLING. 1964. Comparative performance of diallel crosses and related second-generation synthetics of alfalfa. III. Forage yield. Crop Sci. 4: 25-28.

TYSDAL, H.M. and T.A. KIESSELBACH. 1944. Hybrid alfalfa. J. Amer. Soc. Agron. 36: 649-667.

TYSDAL, H.M., T.A. KIESSELBACH and H.L. WESTOVER. 1942. Alfalfa breeding. Nebraska Exp. Sta. Res. Sta. 124: 4-43.

WADDINGTON, J. 1973. Use of factor analysis to investigate relations between environmental variables and forage yield. Can. J. Plant Sci. 53: 309-316.

WALTON, P.D. 1971. The use of factor analysis in determining characters for yield selection in wheat. Euphytica 21: 416-421.

WILCOX, J.B. and C.P. WILSIE. 1964. Estimation of general and specific combining abilities effects and reciprocal effects in crosses among nine clones of alfalfa. Crop Sci. 4: 375-377.

VIII. APPENDIX

DATA FROM 7 X 7 DIALLEL CROSS POPULATION (MEAN VALUES OF 16 PLANTS)

Table I-1. Forage yield - Greenhouse (1971/72) - Grams/plant

Female Parents	male parents						
	1	2	3	4	5	6	7
1	-	9.2	4.4	8.2	8.5	5.5	5.5
2	11.0	-	8.2	8.1	6.6	7.3	8.3
3	8.4	4.9	-	5.6	6.8	8.8	6.2
4	8.5	7.9	6.5	-	7.2	6.4	7.2
5	5.3	4.6	6.8	6.8	-	5.5	3.4
6	9.9	10.8	6.9	6.8	7.1	-	6.5
7	9.0	8.2	7.0	6.1	7.9	7.2	-

Table I-2. Forage yield - July, 1972

1	-	76	54	61	66	62	69
2	79	-	96	66	72	68	62
3	81	56	-	85	78	77	76
4	82	69	73	-	83	85	86
5	62	49	86	71	-	70	76
6	85	84	84	75	72	-	59
7	85	83	87	85	78	74	-

Table I-3. Forage yield - July, 1973 - Grams/plant

Female Parents	male parents 1	2	3	4	5	6	7
1	-	134	185	184	214	96	143
2	101	-	213	267	215	155	166
3	184	182	-	370	330	318	298
4	229	273	405	-	305	374	418
5	110	282	366	397	-	344	339
6	167	235	309	365	366	-	353
7	169	230	180	233	427	356	-

Table I-4. Forage yield - September, 1973

1	-	155	117	154	188	149	141
2	144	-	195	238	187	150	215
3	164	174	-	149	191	186	166
4	162	194	199	-	176	212	169
5	127	177	211	197	-	220	176
6	172	194	194	179	216	-	193
7	125	145	155	171	192	191	-

Table I-5. Forage yield - July, 1974 - Grams/plant

Female Parents	male parents						
	1	2	3	4	5	6	7
1	-	136	266	344	300	317	260
2	195	-	254	531	275	306	596
3	318	355	-	228	548	444	340
4	228	548	445	-	454	468	485
5	353	362	520	481	-	413	513
6	390	381	406	457	489	-	547
7	334	577	287	425	399	559	-

Table I-6. Forage yield - September, 1974

1	-	70	74	94	91	88	67
2	57	-	77	76	85	88	146
3	58	76	-	47	85	88	44
4	71	88	76	-	75	70	55
5	97	73	99	79	-	76	70
6	110	97	63	80	67	-	55
7	73	126	46	49	63	61	-

Table I-7. Forage yield - July, 1974 (Parkland) - Grams/plant

Female Parents	male parents						
	1	2	3	4	5	6	7
1	-	30	84	68	70	118	96
2	36	-	141	268	130	138	158
3	92	157	-	160	158	175	180
4	76	282	174	-	130	196	140
5	66	148	154	146	-	115	170
6	124	108	165	186	131	-	168
7	106	156	192	150	172	182	-

Table I-8. Forage yield - September, 1974 (Parkland)

1	-	28	64	100	58	65	68
2	32	-	70	80	70	93	58
3	60	82	-	75	85	90	81
4	36	96	67	-	86	81	51
5	62	60	69	66	-	70	100
6	59	73	100	69	50	-	70
7	74	68	75	52	96	66	-

Table I-9. Forage yield - July, 1974 (Ellerslie) - Grams/plant

Female Parents	male parents 1	2	3	4	5	6	7
1	-	68	158	186	172	190	192
2	58	-	171	179	132	180	245
3	174	163	-	230	178	196	210
4	224	175	224	-	215	251	232
5	162	126	176	231	-	186	238
6	172	182	192	257	196	-	220
7	174	221	214	230	228	248	-

Table I-10. Forage yield - September, 1974 (Ellerslie)

1	-	48	152	156	151	158	142
2	42	-	148	178	162	168	152
3	142	136	-	140	100	160	128
4	146	152	144	-	141	148	132
5	155	172	150	161	-	146	120
6	152	170	130	152	166	-	180
7	150	140	140	126	180	154	-

Table I-11. Winter survival - 1972/74 (out of 16 plants)

Female Parents	male parents 1	2	3	4	5	6	7
1	-	8	10	14	14	10	15
2	12	-	16	16	16	16	15
3	15	16	-	16	16	16	16
4	16	16	16	-	16	15	16
5	12	16	16	16	-	16	15
6	14	16	16	16	16	-	16
7	14	15	16	16	16	16	-

Table I-12. Vigor - July, 1972 (9=good, 1=poor)

1	-	7.0	6.6	6.3	7.4	6.8	6.8
2	7.9	-	7.6	7.3	7.4	7.2	7.2
3	6.9	6.2	-	7.2	7.3	7.7	6.9
4	7.2	6.7	6.8	-	7.1	6.8	7.0
5	6.3	6.4	7.4	6.7	-	7.2	6.9
6	7.3	7.3	7.8	7.0	7.1	-	6.9
7	7.2	6.9	7.4	7.3	7.4	7.2	-

Table I-13. Vigor - July, 1973 - (9 = good, 1 = poor)

Female Parents	male parents						
	1	2	3	4	5	6	7
1	-	4.8	3.2	5.1	5.7	3.7	4.9
2	4.0	-	5.3	6.4	6.1	5.5	6.6
3	4.9	5.2	-	6.7	6.3	6.8	6.1
4	5.9	6.4	6.9	-	6.2	6.7	7.2
5	4.6	6.8	6.9	7.2	-	6.9	6.6
6	4.9	6.0	6.0	7.0	7.3	-	6.5
7	4.9	5.7	5.4	7.2	7.1	7.1	-

Table I-14. Vigor - September, 1973

1	-	7.8	7.8	8.1	8.3	7.9	7.9
2	8.8	-	8.3	7.6	8.1	8.2	7.4
3	7.6	7.6	-	5.8	7.0	6.6	5.7
4	8.1	7.8	6.9	-	6.0	6.6	5.7
5	8.1	7.4	7.3	6.8	-	7.6	6.7
6	8.1	8.5	6.9	6.2	7.6	-	5.3
7	7.6	7.2	5.7	5.3	6.6	5.7	-

Table I-15. Frost-tolerance - September, 1972 - (9 = good, 1 = poor)

Female Parents	male parents 1	2	3	4	5	6	7
1	-	5.2	4.9	4.8	5.1	4.8	5.1
2	5.3	-	5.0	5.1	5.0	5.2	5.4
3	5.3	4.9	-	5.8	5.4	5.4	5.5
4	5.1	5.3	5.7	-	5.9	5.3	6.1
5	4.9	5.4	5.2	5.7	-	5.2	5.3
6	5.1	5.1	5.3	5.5	5.2	-	6.1
7	5.0	5.2	5.5	6.7	5.7	5.4	-

Table I-16. Frost tolerance - September, 1973

1	-	6.9	7.0	7.2	7.2	6.6	7.3
2	6.6	-	7.2	7.6	7.3	6.3	7.2
3	7.6	7.3	-	8.6	8.1	8.2	7.3
4	7.0	7.7	8.3	-	8.6	7.7	8.8
5	7.2	7.9	7.6	7.9	-	7.6	7.7
6	6.6	6.2	7.1	7.7	7.2	-	8.3
7	6.9	7.3	7.9	8.9	8.1	8.4	-

Table I-17. Growth habit - July, 1972 (9 = erect, 1 = prostrate)

Female Parents	male parents						
	1	2	3	4	5	6	7
1	-	7.8	7.6	7.9	8.0	8.0	7.5
2	8.0	-	8.4	7.1	7.9	8.1	6.7
3	7.6	7.9	-	6.0	6.9	6.9	5.4
4	7.2	7.0	6.2	-	5.8	6.5	5.1
5	8.0	6.1	7.1	6.6	-	7.4	6.6
6	8.3	8.1	6.8	6.7	7.5	-	4.6
7	8.1	7.3	5.8	4.8	6.4	6.2	-

Table I-18. Growth habit - July, 1973 (ratio of height: width)

1	-	4.2	4.7	3.5	3.7	4.9	4.2
2	4.6	-	3.9	3.3	4.0	4.2	3.8
3	4.1	4.0	-	3.5	3.3	3.7	2.8
4	3.4	3.9	2.6	-	2.8	3.0	2.6
5	4.3	3.3	2.9	2.9	-	3.1	2.9
6	3.8	4.0	3.1	3.1	3.1	-	2.6
7	4.2	3.6	3.3	2.4	2.8	2.9	-

Table I-19. Plant height-Greenhouse - cms.

Female Parents	Male parents						
	1	2	3	4	5	6	7
1	-	63.5	53.1	60.6	66.9	60.4	55.1
2	68.9	-	66.5	61.8	59.4	57.1	61.8
3	64.4	58.8	-	59.3	53.6	65.3	58.5
4	63.4	58.9	55.4	-	58.6	56.3	53.2
5	53.5	50.0	53.8	52.3	-	53.3	47.7
6	69.8	63.0	57.3	54.0	54.8	-	53.9
7	60.8	60.3	57.8	54.4	59.1	56.5	-

Table I-20. Plant-height - July, 1972 - cms.

Female Parents	male parents 1	2	3	4	5	6	7
1	-	47.5	43.0	39.3	44.5	39.8	37.8
2	50.8	-	53.3	44.5	50.0	49.8	45.8
3	47.0	42.5	-	49.5	47.8	54.8	43.5
4	43.3	43.5	43.8	-	44.0	44.8	43.5
5	42.8	40.0	47.0	41.0	-	44.3	47.3
6	47.0	48.0	47.5	40.8	44.3	-	42.3
7	45.8	43.3	50.0	43.3	48.3	45.5	-

Table I-21. Plant-height - July, 1973

1	-	45.0	34.0	45.5	54.0	36.8	45.3
2	44.8	-	51.3	56.5	55.0	51.3	58.8
3	48.3	47.8	-	61.5	56.3	66.5	51.8
4	52.0	61.0	60.0	-	49.3	61.5	56.8
5	38.3	59.3	59.3	61.3	-	58.3	59.3
6	47.8	56.8	57.8	62.3	63.8	-	54.8
7	46.0	52.8	49.0	57.0	62.0	66.5	-

Table I-22. Days to flower (1st flower) - July, 1972 - from 1st June

Female Parents	male parents						
	1	2	3	4	5	6	7
1	-	38.3	47.8	42.3	43.5	50.5	46.8
2	33.0	-	45.3	48.5	47.8	48.5	51.5
3	41.8	52.5	-	49.3	52.8	53.8	54.5
4	46.8	51.0	55.3	-	52.3	54.8	53.8
5	43.5	58.5	53.8	53.3	-	53.5	53.5
6	47.0	49.0	51.3	58.3	52.3	-	56.3
7	37.3	51.8	53.3	52.0	51.3	54.3	-

Table I-23. Days to flowers (10th flower) - July, 1972

1	-	52.3	58.3	54.3	55.0	59.5	57.5
2	49.8	-	55.3	57.5	55.5	56.8	60.0
3	55.5	58.3	-	57.0	60.5	58.3	63.3
4	56.5	58.0	63.5	-	58.0	60.3	62.0
5	55.3	64.5	59.8	59.5	-	59.8	60.3
6	58.0	57.5	56.8	62.8	58.3	-	61.0
7	52.8	57.5	59.8	60.3	59.5	59.0	-

Table I-24. Days to flower (1st flower) - July, 1973 - from 1st June

Female Parents	male parents 1	2	3	4	5	6	7
1	-	40.5	44.5	34.5	34.3	36.0	33.8
2	40.8	-	40.5	35.0	37.5	37.5	32.8
3	30.5	40.8	-	34.5	32.8	34.8	38.3
4	32.5	36.0	34.0	-	33.0	33.5	35.0
5	36.0	33.8	28.5	29.5	-	30.8	35.0
6	36.0	33.0	31.3	36.0	29.0	-	34.5
7	32.3	37.0	38.5	31.3	32.5	30.5	-

Table I-25. Days to flower (10th flower) - July, 1973

1	-	45.3	49.3	42.7	40.5	45.5	44.0
2	47.0	-	44.5	43.0	44.5	44.8	41.5
3	41.5	44.5	-	41.0	40.0	42.0	44.5
4	42.0	44.3	40.3	-	40.5	39.5	42.5
5	46.3	39.5	37.5	36.3	-	39.5	41.0
6	44.3	41.8	39.5	41.8	36.0	-	40.0
7	43.8	43.3	42.3	39.5	40.0	37.3	-

Table I-26. Leaflet area (stage I) - August, 1973 - cm^2

Female Parents	male parents 1	2	3	4	5	6	7
1	-	2.8	2.2	2.3	2.3	2.3	1.9
2	2.1	-	2.1	1.8	2.5	1.9	2.1
3	2.4	2.3	-	1.6	2.2	1.7	1.8
4	2.1	1.9	1.8	-	1.8	1.6	1.6
5	2.4	2.1	2.4	1.8	-	2.0	1.9
6	2.5	1.9	2.1	1.9	1.8	-	1.9
7	2.2	1.8	1.8	1.9	1.8	1.6	-

Table I-27. Leaflet area (stage II) - September, 1974

1	-	1.8	1.8	1.6	1.9	1.6	1.4
2	1.7	-	1.6	1.4	1.9	1.4	1.4
3	1.5	2.2	-	1.3	1.7	1.6	1.7
4	1.4	1.5	1.6	-	1.8	1.4	1.4
5	1.7	1.5	2.0	1.8	-	1.6	1.4
6	1.5	1.4	1.6	1.8	1.5	-	1.7
7	1.5	1.6	1.7	1.5	1.5	1.4	-

Table I-28. Specific leaf-weight (stage I) - mg cm^{-2}

Female Parents	male parents						
	1	2	3	4	5	6	7
1	-	4.5	4.0	3.5	4.1	3.6	3.6
2	4.2	-	4.0	3.4	3.2	3.9	4.3
3	3.7	3.9	-	3.6	4.1	3.5	3.8
4	3.5	4.0	3.5	-	3.9	3.5	3.7
5	3.5	3.5	3.7	3.8	-	3.4	4.1
6	4.0	3.8	3.7	3.4	3.9	-	3.8
7	4.0	3.6	3.8	3.7	4.1	3.8	-

Table I-29. Specific leaf-weight (stage II)

1	-	4.3	4.0	3.3	3.7	3.8	3.6
2	4.0	-	3.7	3.7	3.9	4.1	4.1
3	3.5	3.4	-	3.5	3.9	3.6	3.5
4	3.5	3.8	4.0	-	4.0	3.5	3.5
5	3.4	3.8	4.0	3.5	-	3.7	4.0
6	3.3	4.0	3.6	3.3	3.5	-	3.5
7	3.6	3.5	3.8	3.8	3.6	3.6	-

DATA FROM 5 X 5 DIALLEL CROSS POPULATION
(MEAN VALUES OF 16 PLANTS)

Table II-1. Forage yield - July, 1972 - Grams/plant

Female Parents	male parents				
	1	7	8	9	10
1	-	65	81	62	35
7	66	-	37	68	74
8	83	35	-	49	66
9	66	84	52	-	77
10	49	82	71	79	-

Table II-2. Forage yield - July, 1973

1	-	99	148	79	388
7	211	-	307	185	221
8	154	362	-	380	181
9	83	262	371	-	131
10	384	133	216	100	-

Table II-3. Forage yield - September, 1973

1	-	86	149	114	110
7	160	-	175	117	140
8	153	125	-	119	80
9	111	153	211	-	103
10	242	135	189	101	-

Table II-4. Forage yield - July, 1974 - Grams/plant

Female Parents	male parents				
	1	7	8	9	10
1	-	301	217	279	521
7	313	-	657	335	296
8	178	586	-	233	343
9	279	357	403	-	331
10	379	405	400	412	-

Table II-5. Forage yield - September, 1974

1	-	72	54	92	58
7	50	-	109	57	51
8	53	67	-	49	71
9	92	59	65	-	82
10	74	68	93	85	-

Table II-6. Forage yield - July, 1974 (Parkland)

1	-	207	191	132	187
7	158	-	244	116	138
8	180	230	-	158	189
9	120	143	134	-	130
10	170	120	160	142	-

Table II-7. Forage yield - September, 1974 (Parkland) - Grams/plant

Female Parents	male parents				
	1	7	8	9	10
1	-	81	85	70	50
7	77	-	63	55	67
8	70	70	-	37	42
9	60	79	40	-	45
10	60	50	60	48	-

Table II-8. Forage yield - July, 1974 (Ellerslie)

1	-	245	153	171	150
7	230	-	362	206	312
8	182	350	-	195	213
9	205	173	240	-	215
10	165	290	220	220	-

Table II-9. Forage yield - September, 1974 (Ellerslie)

1	-	140	104	136	130
7	139	-	144	122	155
8	110	182	-	129	164
9	174	101	163	-	156
10	140	140	163	160	-

Table II-10. Winter survival - 1972/74 (out of 16 plants)

Female Parents	male parents 1	7	8	9	10
1	-	7	10	7	7
7	9	-	13	14	11
8	13	14	-	15	8
9	2	10	15	-	3
10	5	15	14	8	-

Table II-11. Vigor - July, 1972

1	-	3.2	4.1	3.8	3.8
7	4.7	-	5.6	4.4	4.8
8	4.0	5.9	-	4.0	4.8
9	3.9	4.9	6.0	-	4.1
10	2.2	4.2	4.8	3.0	-

Table II-12. Vigor - July, 1973

1	-	4.8	4.1	3.8	3.8
7	4.7	-	5.6	4.4	4.8
8	4.0	5.9	-	4.1	4.8
9	3.9	4.9	6.0	-	4.1
10	2.2	4.3	4.8	3.0	-

Table II-13. Vigor - September, 1973 (9 = good, 1 = poor)

Female Parents	male parents				
	1	7	8	9	10
1	-	7.9	8.0	8.7	8.0
7	8.7	-	7.1	7.2	7.1
8	8.1	6.8	-	7.7	7.8
9	7.0	7.1	7.6	-	8.0
10	8.0	7.2	7.7	7.8	-

Table II-14. Frost tolerance - September, 1972

1	-	5.1	5.0	4.9	4.9
7	5.2	-	5.6	5.8	5.1
8	4.9	6.0	-	5.1	4.8
9	5.2	5.8	5.8	-	5.1
10	4.8	5.3	5.2	5.2	-

Table II-15. Frost tolerance - September, 1973

1	-	7.1	6.9	7.7	6.9
7	6.7	-	8.2	8.0	7.7
8	6.6	8.3	-	-	7.0
9	7.0	7.6	7.8	-	7.0
10	6.1	7.6	7.0	7.1	-

Table II-16. Growth habit - July, 1972 (9 = erect, 1 = prostrate)

Female Parents	male parents				
	1	7	8	9	10
1	-	7.2	6.9	7.8	8.5
7	7.0	-	5.9	5.3	7.3
8	7.4	4.9	-	7.3	8.1
9	7.0	6.3	6.7	-	7.5
10	8.3	6.7	7.1	7.6	-

Table II-17. Growth habit - July, 1973 - (ratio of height:width)

1	-	5.1	4.6	5.1	4.6
7	3.5	-	2.7	3.3	3.4
8	4.0	2.8	-	4.0	4.3
9	3.4	3.5	3.3	-	4.0
10	5.3	3.6	3.5	4.8	-

Table II-18. Plant height - July, 1972 - cms.

1	-	40.3	48.5	44.0	49.8
7	43.8	-	45.3	48.0	47.0
8	48.5	44.5	-	49.8	46.0
9	46.8	47.8	47.3	-	48.5
10	49.8	49.0	45.0	48.8	-

Table II-19. Plant height - July, 1973 - cms.

Female Parents	male parents				
	1	7	8	9	10
1	-	35.5	40.3	31.3	37.8
7	48.8	-	51.3	37.8	46.0
8	37.5	56.0	-	38.3	46.0
9	30.8	42.3	57.3	-	49.0
10	36.0	34.8	44.0	31.0	-

Table II-20. Days to flower (1st flower) - July, 1972 - 1st June

1	-	54.5	43.3	49.0	42.8
7	49.3	-	55.0	54.0	53.0
8	40.8	58.5	-	46.8	51.5
9	43.3	58.5	52.3	-	51.0
10	42.3	56.0	52.8	53.3	-

Table II-21. Days to flower (10th flower) - July, 1972 - 1st June

1	-	63.5	55.5	57.8	55.3
7	58.5	-	59.3	61.5	60.3
8	55.3	63.8	-	56.3	58.8
9	54.5	63.3	60.5	-	62.0
10	54.0	61.8	59.5	62.6	-

Table II-22. Days to flower (1st flower) - July, 1973 - 1st June

Female Parents	male parents 1	7	8	9	10
1	-	36.3	31.3	32.0	32.8
7	40.0	-	32.0	33.3	40.0
8	30.0	31.8	-	37.8	37.3
9	31.8	37.3	29.5	-	36.0
10	34.3	38.0	34.8	37.0	-

Table II-23. Days to flower (10th flower) - July, 1973 - 1st June

1	-	48.8	42.0	46.3	48.0
7	45.3	-	40.5	43.8	45.3
8	36.3	39.5	-	46.0	42.5
9	46.0	43.0	37.3	-	44.0
10	47.0	46.3	41.5	44.2	-

DATA FROM 6 X 6 DIALLEL CROSS POPULATION
(MEAN VALUES OF 16 PLANTS)

Table III-1. Forage yield - July, 1972 - Grams/plant

Male Parents	Female parents					
	1	2	4	11	12	13
1	-	79	70	65	64	64
2		-	83	74	70	75
4			-	70	65	66
11				-	69	66
12					-	64
13						-

Table III-2. Forage yield - July, 1973

1	-	70	192	118	194	146
2		-	156	136	147	280
4			-	340	265	198
11				-	91	102
12					-	120
13						-

Table III-3. Forage yield - September, 1973

1	-	54	120	123	157	104
2		-	131	119	133	150
4			-	152	138	128
11				-	92	87
12					-	110
13						-

Table III-4. Forage yield - July, 1974 - Grams/plant

Male Parents	Female parents					
	1	2	4	11	12	13
1	-	208	203	360	195	105
2		-	337	387	358	380
4			-	306	333	182
11				-	416	182
12					-	394
13						-

Table III-5. Forage yield - September, 1974

1	-	70	50	68	58	45
2		-	71	88	92	62
4			-	75	64	55
11				-	61	73
12					-	76
13						-

Table III-6. Winter survival - 1972/74 (out of 16 plants)

1	-	4	6	11	4	2
2		-	14	13	13	11
4			-	15	14	12
11				-	13	11
12					-	10
13						-

Table III-7. Vigor - July, 1972 - (9 = good, 1 = poor)

Male Parents	Female parents					
	1	2	4	11	12	13
1	-	8.4	7.9	7.6	7.5	7.9
2		-	8.3	7.6	7.8	7.9
4			-	7.7	7.4	7.3
11				-	7.5	7.9
12					-	7.6
13						-

Table III-8. Vigor - July, 1973

1	-	2.0	4.9	3.6	4.1	4.0
2		-	5.0	4.1	5.1	5.0
4			-	6.0	5.1	5.0
11				-	3.7	3.1
12					-	3.9
13						-

Table III-9. Vigor - September, 1973

1	-	8.8	8.1	8.3	8.1	9.0
2		-	7.7	8.1	8.3	7.9
4			-	7.6	7.4	7.6
11				-	6.9	7.9
12					-	8.1
13						-

Table III-10. Frost tolerance - September, 1972

Male Parents	Female parents					
	1	2	4	11	12	13
1	-	4.7	4.8	5.1	4.8	5.0
2		-	5.2	5.0	5.0	5.2
4			-	5.7	5.6	5.3
11				-	5.1	5.1
12					-	5.0
13						-

Table III-11. Frost tolerance - September, 1973

1	-	6.9	7.1	7.1	6.9	7.0
2		-	7.1	7.6	7.1	7.3
4			-	7.6	8.4	7.1
11				-	7.6	7.1
12					-	7.6
13						-

DATA FROM EXPERIMENTAL SYNTHETIC POPULATION

(SUM OF TWO HARVESTS)

Table IV-1. Forage yield - 1974 (Parkland) - Grams/plant

Population	Replications									
	1	2	3	4	5	6	7	8	9	10
5H	33.1	31.4	32.7	26.1	25.0	27.5	34.1	30.0	32.8	27.5
2H	39.7	39.6	39.0	35.1	35.1	27.8	37.5	37.0	26.0	25.1
5L	27.6	21.0	27.3	18.8	16.8	19.9	17.9	21.0	20.0	20.0
Rambler	22.6	33.3	26.8	26.4	23.5	15.6	30.6	29.9	21.0	20.0

Table IV-2. Forage yield - 1974 (Ellerslie)

5H	56.6	58.1	70.6	55.6	70.6	53.4	61.5	51.4	54.7	58.3
2H	57.3	59.2	56.9	66.5	60.2	67.7	69.6	66.4	61.8	63.6
5L	50.0	51.6	64.4	61.5	52.5	58.0	51.5	54.7	59.1	63.5
Rambler	39.1	35.8	39.2	48.5	50.4	50.2	50.9	48.1	52.1	59.9

DATA SHOWING DIFFERENCES BETWEEN REPLICATIONS

Table V-1 Characters in a 7-clone diallel

		REPLICATIONS			
		1	2	3	4
Forage yield (gm/plant)	1972(July)	81	79	72	65
	1973(July)	294	273	254	242
	1973(Sept)	177	174	176	168
	1974(July)	377	378	376	340
	1974(Sept)	75	76	74	72
Vigor (rating)	1972(July)	6.5	7.0	7.4	7.6
	1973(July)	6.0	6.3	6.0	5.7
	1973(Sept)	7.0	7.0	7.1	7.8
Frost Tolerance (rating)	1972(Sept)	5.6	5.4	5.3	5.2
	1973(Sept)	7.6	7.6	7.6	7.4
Winter Survival (%)	1972-74	95	94	96	95
Growth habit (rating)	1972(July)	7.0	7.1	7.1	6.9
	1973(July)	3.5	3.6	3.5	3.6
Plant height (cm.)	1972(July)	46.2	46.1	47.4	41.4
	1973(July)	57.0	56.2	52.1	50.2

Table V-2 Characters in a 5-clone diallel

		REPLICATIONS			
		1	2	3	4
Forage yield (gm/plant)	1972 (July)	72	74	70	64
	1973 (July)	172	177	175	166
	1973 (Sept)	132	131	134	128
	1974 (July)	343	344	342	339
	1974 (Sept)	71	70	70	68
Vigor (rating)	1972 (July)	6.3	6.8	7.1	6.4
	1973 (July)	6.2	6.5	6.5	6.8
	1973 (Sept)	7.8	7.2	7.7	7.1
Frost Tolerance (rating)	1972 (Sept)	5.7	5.1	5.2	5.9
	1973 (Sept)	7.7	7.6	7.5	7.4
Winter Survival (%)	1972-74	80	85	83	88
Growth habit (rating)	1972 (July)	7.1	7.5	7.2	7.3
	1973 (July)	3.6	3.7	3.2	3.6
Plant height (cm)	1972 (July)	47.5	42.1	43.6	41.5
	1973 (July)	56.8	55.9	52.3	51.2

Table V-3 Characters in a 6-clone diallel

		REPLICATIONS			
		1	2	3	4
Forage yield (gm/plant)	1972 (July)	70	75	72	63
	1973 (July)	168	169	162	160
	1973 (Sept)	125	126	120	118
	1974 (July)	295	311	307	301
	1974 (Sept)	69	68	66	62
Vigor (rating)	1972 (July)	6.4	6.1	6.8	6.5
	1973 (July)	6.3	6.2	6.1	6.7
	1973 (Sept)	7.9	7.5	7.5	7.6
Frost Tolerance (rating)	1972 (Sept)	5.6	5.2	5.5	5.4
	1973 (Sept)	7.8	7.5	7.9	7.6
Winter Survival (%)	1972-74	64	65	66	65